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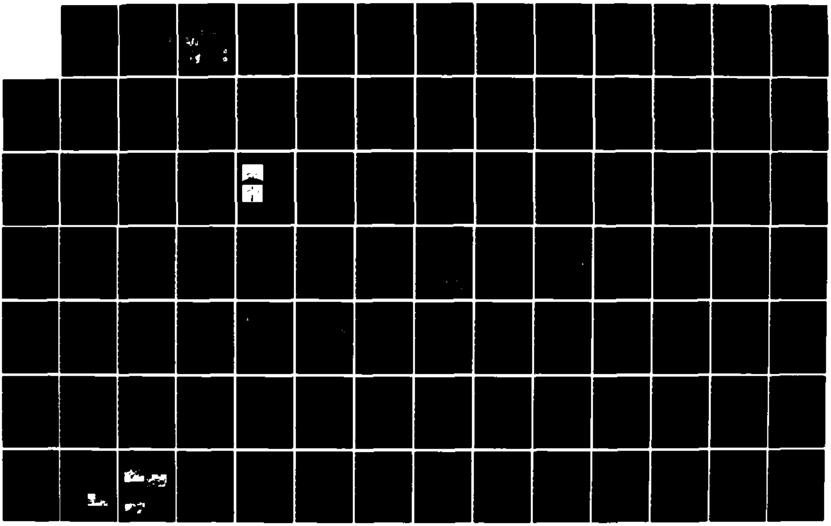

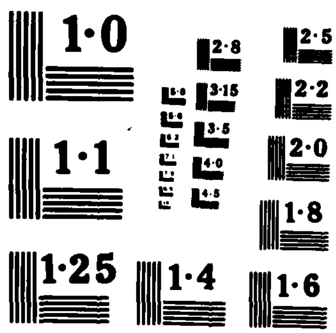
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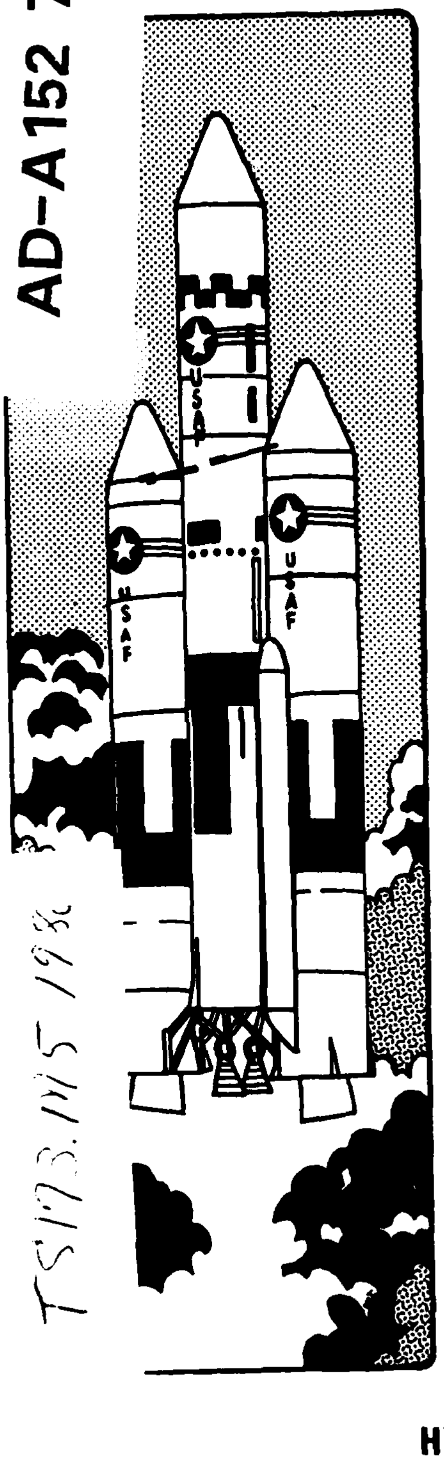

- PROGRAM MANAGEMENT
- DESIGN
- SUBCONTRACT MANAGEMENT
- TEST EFFECTIVENESS
- PIECE PARTS MANAGEMENT
- MICROELECTRONICS
- CRAFTSMANSHIP
- CONTRACTUAL INCENTIVES
- DEVELOPMENT PROCESS
- COMPUTER SOFTWARE/ RESOURCES
- RFP/SOW
- MOTIVATION AND TRAINING

National Security Industrial Association

Aerospace Industries Association

Space Division

NASA

HYATT HOUSE - AIRPORT
LOS ANGELES
28 APRIL - 2 MAY 1980

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OBJECTIVES

PROJECT

In April 1978, a Mission Assurance Conference was sponsored jointly by the Air Force Space Division, and Industry to discuss fundamental issues that would enhance spacecraft mission success. The 1978 Mission Assurance Conference resulted in the implementation by management of many of the recommendations generated in the conference. Because of the success in 1978, the Space Community consisting of Air Force Space Division, NASA and Industry Associations (NSIA and AIA) have mutually agreed to conduct Mission Assurance-1980 to further explore the issues affecting both Government and Industry which inhibit mission success on Space Programs. Issues in program management, design, procurement craftsmanship, test effectiveness, motivation, development process and in other areas affecting mission success will be openly discussed and analyzed in workshops with audience participation. The final objective will be recommendations from the workshops directed at both Government and Industry management for implementation.

GOALS

- Identification of obstacles and counter-productive practices having an effect on mission attainment.
- Development of cost effective approaches or better utilization of information and resources to enhance mission success.
- Determination of new or better application of existing techniques providing a forcing function to mission risk minimization.

CONFERENCE

The purpose of this conference is to provide the broadest exposure and most time efficient means of exploring significant tasks necessary to achieve mission assurance. This conference allows us to utilize the aggregate technical and managerial talents of Government and Industry to provide recommendations and guidelines in areas of their major concern.

The conference objectives are to:

1. Stimulate exchange of ideas between Industry and Government on management/technical/acquisition support aspects of mission assurance.
2. Provide a forum through which the total community can impact and address problem areas.
3. Provide a continuance to the 1978 SAMSO/Industry Mission Assurance Conference.

CONFERENCE ORGANIZATION

Conference Chairmen

Col. Norman E. Niederman, Space Division
Harry Quong, NASA Headquarters
Joseph S. Dintino, Honeywell Inc.

Planning Committee

M.A. McGowan, Aerospace
Gerald E. Lutz, Fairchild
John Morey, Hughes
Paul Burdeno, Space Division
Lt. Col. Ken Blakney, Space Division
John Grosvenor, TRW
Jack Reberry, Space Division
Dr. Don Dooley, Aerospace
Brooks Morris, JPL
Edward Newman, Space Division
Ernie Hayes, General Dynamics
Michael Butler, MDAC
Andrew Pond, Space Division
James Egan, Aerospace
H.S. Moore, NSIA
E.A. Schecter, RCA

Session Coordinators

D. Lindstrom, Hughes
D. Browne, Space Division
H. Lange, MDAC
F. Speigl, Space Division
R. Berri, Aerospace
E. Newman, Space Division
M. Butler, MDAC
W. Courtwright, Hughes
H. Sharp, Space Division
L. Jepson, Space Division
J. Wiesner, Aerospace
B. Evans, TRW
A. Carlan, Aerospace

Finance/Registration

P. Cole, NSIA
H. Moore, NSIA

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AIR FORCE KEYNOTE ADDRESS

Lt. General Richard C. Henry
Commander, Air Force Space Division

Good afternoon, ladies and gentlemen. I join those who have preceded me in welcoming you to our second mission assurance conference. The goals of this meeting reflect the sense of team effort that is the only true key we have found to mission assurance.

The importance of this team effort leads me to suggest that the theme for this second conference might be "The Human Equation."

It is the human equation, or the human factor, that is most important to mission assurance and success. The human equation is reflected in teamwork, in craftsmanship, in pride and in a job well done - and in a sense of responsibility for one's product, whether that product is an RFP or an integrated circuit.

If, in the collective wisdom of the experts who are here for the next five days, we find the key to the vault which houses the secret to achieving teamwork and workmanship - then the funds invested in this conference are, indeed, well spent.

In our history chapters, we have some striking examples of teamwork and pride of craftsmanship that have given us mission assurance. I'd like to describe one or two to illustrate that it can be done. And I'd also like to give an example of how not to do it.

In early May of last year, Mr. James Deering, an employee at Martin-Marietta was inspecting hydraulic tubing on the first stage of a Titan III space launch booster. He noticed a large chip or flake inside the tube approximately two inches from the end. The condition resembled chrome peeling from a car bumper. This could become a very serious problem if the "chips" were to break off and get lodged in a pump or reservoir.

Immediately, the Martin-Marietta engineers inspected the tube stock - and they found that three out of seven half-inch tubes had similar problems. All other contractors using this tubing rapidly became involved. Working with Martin-Marietta, Aerospace Corporation, and our Titan Program office, the team ascertained what size tubing was being affected. They determined whether a potential for a catastrophic failure was involved, and they established a criterion for acceptance of new tubing. More importantly, they identified the causal factors.

You can imagine the difficulty of inspecting tubing after it has been formed. A very tedious, time-consuming methodology was developed because we had to assure the quality and integrity of the hardware. This methodology was developed and implemented with the full cooperation and collective wisdom of everyone involved, especially the contractor.

Next, we decided we needed to change out the tubing on the vehicles that were already stacked at both the east and west coasts so we would have the best chance of mission success. We had not done this before - changing out hydraulic tubing on the pad - and we needed to make sure we did it right. Finally, we had some launch windows we had to meet. Everyone involved - the engineering, management, and production people - worked twelve-hour shifts and devoted their weekends in order to meet the schedule...

The culmination of this effort was that both launches met their windows - and both launches were successful. That is the kind of work it takes to get mission assurance.

As an aside, all tubing that Martin-Marietta had in stock met the mil-spec. But we did put out a crosstell throughout industry to protect against recurrences in the future.

This is an example of teamwork that gave us mission assurance in the true sense of the term.

And it was accomplished without a warranty, without an award fee, and without negative or positive incentive fees. It was accomplished by a successful human equation - people working together who took pride in (and responsibility for) their work.

I can say that, early on, it was my distinct privilege and pleasure to send a personal note to Mr. John Deering at Martin-Marietta, commending him for a conscientious job well done. Let me describe another case - a situation where

a situation where things didn't go so well.

On another program, some propellant properties were outside of specification. Studies were conducted to improve the formulation; as a result, representatives from the contractor, the subcontractor, and the government got together and agreed formally on the definition of the propellant formulation and the processing criteria.

One of the processing criteria involved controlling the end-of-mix temperature. One of the subcontractors stated that end-of-mix temperature could be controlled within three to five degrees fahrenheit, and the company did not request a waiver to or change in the specification temperature.

On the very next batch of propellant, the end-of-mix temperature exceeded the spec limit that had been agreed to. This out-of-spec condition was processed as a normal material review board action - and the program office was not notified until after the propellant had been poured into the motor.

Although there was no violation of procedure as such, there was a violation of the spirit of good working relationships because the representatives who had concurred in the formal agreement were not the technical people who processed the review board action.

Since that time, we've made a strong effort to weld together an effective government-industry team to prevent similar situations in the future - and it has worked well.

In fact, that same government-industry team has been actively involved in cooperative and creative problem-solving. When we had a failure during a volume simulator ignition test, we lost a solid rocket motor case - and we suddenly had a scheduling problem.

Fabrication of another case would have been both time-consuming and costly. In order to obtain another case and preserve the schedule, the government, the contractor, and the subcontractor agreed to limit the skirt load test to 155 percent of design limit load on the last motor case - if the stress-strain curves during test followed the same trends as in the previous test. The specification called for "Test to Failure."

All of the parties involved witnessed the test. The conditions of the agreement were met - and the case was preserved for future testing with no detrimental effect on the program.

These are only three examples. There are many more - on both sides of the ledger - that all of you can recall from your own experiences.

I'd like to share another recent experience with you that illustrates once again the importance of the human equation.

One of our program offices recently presented a mission readiness review for a spacecraft launch. The program office had kept book on all component failures during the final test flow and had tracked down the cause of failure in each case.

The statistics were interesting. Most of the causes of failure had by now reached a certain noise level. But workmanship showed a curious phenomenon.

On the five previous spacecraft, workmanship flaws were on the decrease - as one would expect - a learning curve, if you will. Yet, on this spacecraft, they showed a marked increase.

I should also mention at this point that these workmanship flaws were on components that had already passed acceptance tests and had been installed on the spacecraft.

We found this phenomenon most perplexing. We don't know that we really understand the cause - most probably, the number of flaws increased because of a turnover in people on the assembly line at the vendor's plant.

But, whatever the cause, I've just described what, in my view, is the larger challenge of this conference. How can we overcome the innate imperfections of the human being? How can we define the human equation that gives us teamwork and craftsmanship and rejects mediocrity - the human equation that refuses to work at the lower end of the specification?

We know that it can be done - I've just described some cases which illustrate that...

I suggest the answer is not in the contract terms, although that can help. I would also suggest that reward is more important than punishment. But overriding all of these factors is the leadership in industry and government that breeds teamwork.

Leaders create an atmosphere of pride and of excellence; they are the ones who set an example for others to follow. Their actions and words demonstrate that mediocrity is unacceptable and that teamwork is essential; their pride in their jobs is contagious.

In our business, we cannot settle for less than the best - the highest standards and the greatest pride in workmanship.

The cost of failure is too high. We know we have to do it right the first time. We know there is no recall after we light the fuze. We know that we can't afford to do it over....

These are the more unusual characteristics of this trade known as the space business.

I am proud to see so many of you here this week. Your presence is indicative of your interest in our success.

Our record is a good one - and one that we want to make better. If we can do that, we will be providing our customer - your families and mine - a better return on the investment of their tax dollars. But, more important, we'll be making a larger contribution to their freedom.

With those common motivations, we cannot help but have a good conference here this week. Thank you for coming - and help us work the human equation.

INDUSTRY KEYNOTE ADDRESS

James W. Plummer
Executive Vice President
Lockheed Missiles and Space Company

MISSION ASSURANCE CONFERENCE

J. W. Plummer Speech
Hyatt House, Los Angeles
April 28, 1980

Considering the nature of this meeting and the organizations represented, I believe that it is safe to assume that most of the people present devoted their time in college to the fields of science and engineering. However, I suspect that in such an education that each of you was required to take at least one course in psychology. Well, if you did, somewhere in the text of material that you studied, you encountered the story of Pavlov's dogs.

In Pavlov's classical experiment he took a very patient dog and installed him in the apparatus shown in order to record data on the dog's reaction to a stimulus. In this case the stimulus being food and the reaction being saliva which was trapped and measured. The dog was hungry, the dog would see food; it would salivate automatically. Then the experimenter rang an electric bell each time the food was present and, of course, in a short time the dog reacted to the bell just as he had originally reacted to the food. To summarize: an unconditioned stimulus caused an unconditioned response. Later with the bell - a conditioned stimulus created a conditioned response.

At Lockheed we have been concerned about the general area of productivity and have an ongoing program dealing with employee motivation. We have retained a very talented industrial psychologist, Dr. Ed Ruda, basically to assess our managerial capability and provide group counseling in the area of motivation for productivity. Group therapy no less - perhaps better called group psychotherapy. In his work at Lockheed, Ed Ruda develops, in a series of sessions, the eight principles which are a guide to almost all of human behavior. However, he emphasizes two basic principles, and he quotes them using characteristic scientific terminology as follows: "If a person behaves and gets rewarded for that behavior, the behavior will happen again." Transferring that to the typical manager-subordinate relationship, "To the degree your subordinates are rewarded for an action, that action will happen again." But to have continued "action" you must provide repeated reward, that is reward - action, reward - action.

The second "theorem" in two parts: "If a response to a situation is followed by a mild negative reaction, the response will be less likely to happen again. If a response to a situation is followed by a strong negative reaction (punishment), you do not create an effective change in behavior."

I am sure that most of you people here have heard these "theorems of psychology" before. I suspect that most of you believe that as you interface with other people, subordinates, family and friends, that you try to utilize these principles. However, most of us, in an objective and private inventory of our recent actions, would have to admit to some deficiencies.

Recently on one of our local broadcast radio stations a situation was described which relates to what I have been talking about here today. It seems that the high level of health care available today has reduced the number of people who become blind. As a consequence, there is not as much demand for Seeing Eye dogs. Some innovative person got the idea of training these dogs to assist the deaf. The dogs have to learn to identify a baby's crying, a doorbell, telephone or smoke alarm.
The American Humane Association is expert in training dogs but found this task much more difficult than that required for the typical Seeing Eye dog and they went back to analyze the basic principles of dog training. In the process they showed that the most common dog training technique, namely the commonly used choke chain is not an efficient training method.

This type of training was identified by these experts as the "pull and jerk" type management. It is obviously negative reinforcement and may verge on punishment. The results are slow training and constant negative reinforcement to maintain training levels.

But, what has all of this to do with the subject of this symposium, "Mission Assurance?" Here we have an agency of our Federal Government, the United States Air Force, dealing through one of its major commands for the acquisition of equipment or services from a corporation.

The corporation in turn probably consists of thousands of people and a very large organizational structure. Kind of impersonal! But of course once the project is assigned, it is run in the military department by a Colonel or Lieutenant Colonel assisted by a military staff and possibly some civilian experts. And on the contractor's side, it is a program manager assisted by a group of engineers and shop people. These government and contractor people in their day-to-day interactions throughout the entire period of performance must behave in accordance with these principles to maximize motivation, improve productivity, and, ensure mission success.

The question is: Does the SPO in dealing with his prime contractor use modern motivation practices or does he use "pull and jerk" management principles? How about AFPRO personnel in surveying a contractor's operations for purposes of contract administration? How do we prime contractors deal with our subcontractors? How do we all treat our subordinates? In all of the above we could impove motivation and achieve major steps in productivity if we were to go back to the common sense principles of dealing with people.

I have had the good fortune in my professional years of working in the engineering department, as a program manager, as a subcontractor, as a prime contractor, and even for a short time on the other side of the table, with the Air Force. In that process I have observed a great many projects, some good and some bad - some that achieved their mission objectives and some that failed. One strong positive correlation throughout this review of my inventory of programs has been that where there was a good solid professional "teamwork" established between the government agency and the contractor, the program was successful.

Several months ago two of our LMSC experienced and successful program managers reflected on the problems that we had experienced with subcontractors. How should we get our message across to them on the types of management systems we expected from them and the control systems that we wanted them to implement? Were we being consistent in our communications with them as we collectively dealt with their contracts manager, program manager, controls manager, and project engineers? Were we listening to their responses to ensure that the communication was effective? Were we motivating them by rewarding them in some manner for good actions and were we properly handling the unsatisfactory situations? In short, were we building a team? These reflections and the analysis thereon led to the generation of a management tutorial to be used as text of a training program for our own people for the proper control of our subcontractors.

In discussions with General Henry relative to the role I might play in speaking for industry at the opening session of this conference, he suggested that I "tell the Air Force people present what they might do for the contractors in support of the common objective of mission assurance." With such an invitation I could not turn down the opportunity to use the forementioned training to suggest to the Air Force senior officers, contracting officers, and SPO's alike, things they might do to provide for the kind of working relations that will ensure good program performance. These suggestions will be under the banner of "Secrets of a Successful Customer."

Under the guidelines of the famous DoDD 5000 series of documents for acquisition, the modern military customer has good access to information of what is going on at his contractor's plant. But no matter how ingenious the computer program or how well structured the organization, the SPO is, in large part, dependent on information being volunteered to him by the contractor personnel. Assume the contractor program manager comes to you with information of an increased overrun or of a slipped schedule, or that the very critical first development article has been damaged by dropping it from a forklift truck. How do you react?

The natural reaction is to vent a few of your true feelings, and the fact that the program manager is made to look totally ineffective in front of his peers simply drives home the seriousness of the situation. But the problem from this unconstrained reaction is that program manager will probably never again come forward willingly with negative information. He would probably not lie or deliberately cover up information which is required,

but he certainly would do his best to solve the problem before he brings it to you. This takes time and sometimes results in a far more serious situation. Therefore, the obvious - don't behead the bearer of bad news!

The proper solution, of course, is to have such a close working relationship with the company program manager and a mutual sharing of responsibility on the overall program that you will know almost as soon as the program manager does of both the positive and negative aspects of the program. Should it be necessary to lay on the law, and this of course is sometimes necessary, it should be done privately so as to continue the relationship as team members. Remember the psychology rule - be mildly aversive to correct bad behavior. Use punishment carefully - and infrequently.

Many years ago when I was standing vigil over one of our satellite projects in the Air Force Satellite Test Center with General John Martin, we talked about the relative capability of contractors supporting Air Force programs. He made a statement which I will never forget as follows: "Remeber, companies do not have experience, people have experience." It is vital when you start a new program to identify the key players on the contractors team and go through the process of identifying strengths and weaknesses of each person. Identify those who are inherently pessimistic and those who are eternally optimistic in order to provide adjustment factors on information given by these individuals.

You should try to understand that a contractor person, whether an engineer, program manager, or vice president, has a set of pressures somewhat different than yours in the military world. Such understanding will help to provide for good communication and trusting relationships.

Finally, considering all of the above, identify an individual or an organization that is best to get your message to the total contractor organization President to support Manager. Generally, I believe that person is the program manager, although sometimes it could be the contracts man, the marketeer, or even one of the vice presidents. He is a person who has a unique personality, ability to listen, and a capability for communication within his own company; in other words, management listens when he speaks to them.

In today's very competitive environment, we contractors study your RFP very carefully and have a good grasp of the organization you propose to run the program. I believe that most contractors fairly well duplicate that organization within their own shops in order to identify counterparts and encourage communication. But considering the earlier point of identifying the key players, both the contractor and the government must work to identify organizational parallels and establish close working relationships for each. All good managers delegate responsibilities to the lowest possible level. More important is that we encourage communications to counterpart organizations at the lowest possible level.

This suggestion has to do with getting around and being visible to the contractor personnel as an important factor in motivating the people who are doing the work. We know it works well within our own shop. For example, with our own management, the simple act of walking around and seeing people and talking to them about what's going on in their particular area, is very effective for improving motivation and morale. The impact that you as a customer have at those levels is one that would probably surprise you - maybe even scare you if you knew how really effective it can be. One little pat on the back for a fellow on the production line can work miracles in motivating that individual for several weeks or even several months.

Positive reinforcement is your most effective tool. And in the process of "tramping the orchard" you can learn things about your program that you cannot get in any other way. You are, in effect, doing the same thing a good program manager does with his people, and the data so obtained can be used in your discussions with the program manager to solve mutual problems. You build up friendships at all levels in the organization and these individuals like to talk about their problems and their successes. Compare this type of communication to the formalized quarterly program review which sometimes turns out to be a recitation of data from

a chart by a person who doesn't really understand the facts.

You, as the responsible government agent in dealing with your contractor, have a number of means to convey your prime objectives. The contract can state them explicitly, you can write letters, you can have mass motivation meetings, and you can have informal contact. All these techniques can be used to lend extra emphasis to your prime objectives. Of course these objectives must be well thought out and represent your true mission priorities. The current management technique of "management by objectives" often times includes all that is good and avoids all that is bad. Proper objectives should prioritize the things that are most important and identify other factors that might be sacrificed to the achievement of high priority targets.

In preparing for this conference I reviewed the proceedings of last year's Industry-SAMSO Conference, and noted that from the opening remarks of General McCormick, Jack Townsend, and Ed Rechtin, on through the meeting there was a very substantial discussion of the use of contract incentives on mission assurance.

Workshop B under Colonel Ken JuVette was one of the best discussions of the mechanisms of contract incentives and product assurance that I have read. Although I personally feel very strongly about the high value of contract incentives for mission assurance, I will not belabor the issue here. Clearly, if awards are involved they must be specific; measured without resorting to complicated formulas and be inherently motivating.

There are many cartoons depicting the program manager. My favorite is the individual called "Program Manager" standing in a lion's cage surrounded by three snarling cats. One with the caption, "Cost"; another caption "Schedule"; another caption, "Performance." How he handles that trio of problems determines whether or not he will get out of the cage and proceed up the management ladder. The fellow depicted here faces the same problems. In most companies the program manager has essentially the power of the general manager on all aspects pertaining to the program. Clearly, he is devoted entirely to your interests and it is vital that you understand that his career depends on your performance. On the other hand, your career depends equally on his performance. It is a full time commitment for both.

In the same vein you should not use the program manager for things that can be done equally well by special assistants such as a company contracting officer, security officer, or other specialty areas. You, as the "boss" of the situation, particularly during the early honeymoon days of the SPO-contractor relationship, can insist that the program be adequately organized to handle all of the specialty areas.

Through the efforts of a very large number of experts over the years we have generated a number of management systems which have great value to modern programs - if used properly. Without going into the details so obvious to most of you, we must not rely on systems or computer programs to do our management job. Clearly, the computer is the best tool available to us to keep track of vital data. Beyond the obvious high cost of implementing special computer systems for the control of the program, there is the fact that the maintenance and operation of such systems do take much of the valuable time of the team that might better be used in solving problems. A large quantity of reports and data do not guarantee visibility.

I want to thank you for your attention to my narrating these ten commandments of a successful customer.

In my opinion the acquisition methods practiced by the United States Air Force are outstanding. The very large number of complicated programs that have been brought on line is a tribute to both the military management and the contractors that have formed the teams. I do not believe that the government uses "pull and jerk" techniques. I believe that most of our government and contractor actions recognize positive reinforcement - but it doesn't hurt to go back to fundamentals. The best sources of motivation for increased productivity and for mission assurance are: positive reinforcement, praise, and reward...again and again.

NASA KEYNOTE ADDRESS

Dr. Walter Williams
Chief Engineer, NASA

MISSION ASSURANCE CONFERENCE

Remarks by Dr. Williams
Los Angeles, CA
April 25, 1980

I'd like to welcome all the attendees on behalf of NASA's administrator, Dr. Robert Frosch, to the 1980 Mission Assurance Conference. Dr. Alan Lovelace, our Deputy Administrator, had desired and intended to be present to give this keynote address but the press of business, budget decisions, etc. prevented his attendance.

NASA believes strongly in the usefulness of the conference as is evidenced by out co-sponsorship and by our co-chairmanship of many of the panels.

NASA's enthusiasm for the project is not based on mere optimism but on the very real benefits which accrued to both industry and government and their working relationship as a result of actions stemming from the conference of two years ago. As stated in the brochure, one of the conference objectives is to "stimulate exchange of ideas between industry and government on management/technical/acquisition support aspects of mission assurance." NASA believes that it is essential to openly discuss key issues in all the disciplines that are impacting mission success from the assurance standpoint. Unlike other conferences, this one requires you, as groups and panels in the workshops, to develop realistic recommendations for implementation by industry, Air Force, and NASA. This is your opportunity to speak out and be heard.

Since this is billed as a keynote speech and since details will be capably and thoroughly discussed in the various panels, I will limit myself to the overall objectives of this conference from the NASA viewpoint and to relating to you some recent "Lessons Learned" on the Space Shuttle and other NASA programs as applied to mission assurance and mission success.

In his letter of invitation to the Aerospace leadership and to the NASA Center Directors, Dr. Lovelace suggested two core questions which I feel should be kept in mind as overall objectives during all the activities and panel meetings of the conference. Those two questions are:

1. How can we improve mission success and

2. What can be done to develop improved and cost effective methods for using information and resources to enhance mission success?

I'd like to add a third core question for your consideration during your workshop discussions. This question is:

> Why can't we be more effective in applying "Lessons Learned" from past space programs for mission assurance?

Keeping those basic questions in mind, let me give you a few of my own thoughts which might contribute to useful answers. Mission Assurance is not simply a matter of Reliability and Quality Assurance but includes a variety of other functions such as:

(1) Good program management

(2) Optimal design, testing and development processess

(3) Adequate screening of parts

(4) Realistic parts programs

(5) Realistic Request for Proposal (RFP) and Statement of Work (SOW)

(6) Good materials control

(7) Effective contract incentives

(8) Effective monitoring of subcontracts materials and pricing problems

(9) Continued motivation and training of management and operating personnel

(10) Subcontract Management

The list of assurance functions can go on and on. The key point I want to make is that mission assurance encompasses everyone involved in a program. I am pleased to see that this conference is covering the many disciplines from program management to contract incentives to test

effectiveness. It is essential that the messages of mission assurance reach that congregation not just the choir. Let me discuss some of these functions as related to mission assurance.

We have used all sorts of contract incentives from Cost-Plus-Fixed-Fee to Cost-Plus-Award-Fee to Fixed-Price with In-Orbit Performance Award for the purpose of motivating contractor's performance. However, we still have design problems, manufacturing defects, poor workmanship, vendor problems, materials problems, etc. We have not been able to translate contractural incentives for contractor's performance to people's performance. I'd like to see the 3 workshops on contract incentives, craftmanship and motivation explore the possiblities of relating contract incentive to people's perfomance. I don't mean Zero Defect. Subcontract management seems to be a continuous source of many of our mission assurance problems. We have been able to maintain good visibility on what is going on at the prime contractors. But at the subcontractor, vendor and supplier levels we do not have the same visibility for mission assurance. We are relying on certificates of conformance, vendor audits, periodic source inspection to provide to us a warm feeling that things are OK. But the feeling is not too warm. Over the years, we have had problems in counterfeit parts, inadequate processing of materials, mixed materials, deliberate material substitution, etc. I'm not sure if the present practices of subcontract management are adequate. I see from the program brochure that the conference has a workshop called "Subcontract Managment-Looking Up and Looking Down." I hope this workshop will address the improvements we need in sub-contract management so that we have the visibility for mission assurance.

I believe that it is essential for us to explore new and better ways for mission assurance. However, we have not taken the "Lessons Learned" from previous space programs and applied what we learned in other areas and other programs.

Let me give you some recent examples of problems and hopefully some "Lessons Learned" from these problems for your consideration during your workshops.

<u>The Reynolds Aluminum Plates with Soft Spots.</u> I'm sure most of you have heard of this problem. The impact of defective aluminum plates was worldwide affecting commercial and military aircraft and the space program. A major investigation resulted in screening of aluminum plates, revision of inadequate military specifications, increased government and industry inspection, implementation of process control at the mill, etc. Also, we found that conductivity tests and limits were not adequately defined. This particular problem is being taken care of but what are we doing about the "Lessons Learned"? We should re-examine the adequacy of other material specifications and NDE methods. We should consider ways of verifying to accuracy of certificate of material conformance. We need to apply the "Lessons Learned" from this problem to prevent major problems in other materials areas.

<u>INCO 718 Weld Wire Problem</u>. Some of you may not be aware of this problem but NASA lost a Space Shuttle main engine because of mixed weld wire material at supplier. And this problem is not restricted to a single supplier. The loss to NASA is not just a monetary loss in the millions of dollars, but also in the loss of valuable time in the development of the Shuttle. Although the root cause of the problem was traced to a lack of quality control at the vendor, the mixing of weld wire was known to several aerospace companies, but not reported via the GIDEP Alert System. The "Lessons Learned" from this example is that aerospace companies should have alerted other companies of the mixing of weld wire materials. Prime contractors' surveys of the wire manufacturers should have uncovered inadequate process and quality control. We should maintain visibility at third and fouth tier vendors and suppliers for mission assurance. This is not a new problem. It is my understanding that mixed weld wires have occurred in the past but we have not applied the "Lessons Learned" from the past.

<u>Space Shuttle Thermal Protection or the Shuttle Tile Problems.</u> In this particular case, I'm sure all of you in the aerospace community are aware of our problems associated with the Thermal Protection System (TPS). The tile and

other Shuttle problems are keeping Dr. Frosch and Dr. Lovelace awake at nights. From a thermal protection standpoint, the tiles are superior to the materials used in the past. However, we are having problems in process control, in material control, in inspectability, etc. In designing the TPS we did not consider the problems in installing the thousands of tiles, in making sure the tiles are glued properly, in the handling process, etc. The "Lesson Learned" from this case is that in the development process from the paper to the product, all the assurance functions must be considered in order to prevent inherent problems.

Cracked B-nuts Sleeves. Recently during final tests at the Kennedy Space Center on a launch vehicle we found some cracked B-nuts sleeves. This resulted in a launch delay, which is very costly. Investigation of the cracked sleeve problem revealed that the material was sensitaized. Further investigation found wrong and sensitized materials at more than one vendor. Like the mixed weld wire problem, cracked sleeves have been with us for a long time. We have taken appropriate corrective action each time the problem comes up but we have not applied the "Lessons Learned" to prevent the problem from happening again. The examples I have cited are real problems and have occurred previously. Each time it happens, we put a Band-Aid on, but we have not reached the root causes to prevent the reccurance of the problem. These are not just mission assurance problems but mission success problems. The survival of NASA is dependent on the success of developing a Space Transportation System. This requires mission assurance functions from top program managers down to the floor workers at the lowest vendors covering all disciplines.

With the framework of the three basic questions posed earlier I hope all the workshops consider the "Lessons Learned" from past and recent programs in:

(A) Realistic recommendations for implementation by government and industry.

(B) Better communications and improved government/industry working relationships; and

(C) The exposure of middle management in all disciplines in both government and industry to mission assurance problems.

I am looking forward to Friday to hear your recommendations on mission assurance.

PANEL
PAST AND FUTURE CHALLENGES
OF
MISSION ASSURANCE

Chairmen

Dr. Eberhardt Rechtin
President
The Aerospace Corporation

Paul Wright
Vice President and General Manager
RCA Astro Electronics

Introduction by

Gerald E. Lutz
Director, Quality Assurance
Fairchild Space and Electronics Company

Panelists

Merland L. Moseson
Director, Flight Assurance
Goddard Space Flight Center

John Housego
Space and Communications Group HAC

Thomas A. Meaker
Product Assurance Manager
European Space and Research Organization

SPEECH - MISSION ASSURANCE CONFERENCE

Dr. Rechtin

The central mission assurance problem of Space Division and Aerospace, as one of its principal advisors, is that about once a month we have to certify readiness for launch. The certification risk typically averages $200 million per crack.

Since the last Mission Assurance Conference two years ago, we have had good performance on orbit; there have been no launch failures. The Titans, Atlases, Thors and Centaurs have all gone well. It's a remarkable record - an unsung story, really. Those vehicles are now approaching 30 years of active life as launch vehicles - something which I think we can look forward to for the shuttle as well. The spacecraft record also over the past two years has been quite remarkable. I think by anyone's standards we can give 4 stars to a number of programs. The ones which I am particularly impressed with are the TRW DSCS II's, the NATO III's of Ford Communications and Aerospace, TRW's FltSatCom and Rockwell's GPS R&D phase. Every one of these are quite remarkable. Looking retrospectively, defense communications satellites used to be in some disrepute but over the last some years on-orbit performance by those spacecraft is virtually flawless. FltSatCom is one of the most astounding successes to come down the pike in a long time. There are other programs that have done quite well - the STP, the DMSP and others. There have been almost no spacecraft that have not at least reached mission design life and most of them have done better than that.

However, that was the good news. There have been a number of fairly serious anomalies, some of them on orbit. Most anomalies, as has been earlier shown by NASA, occur on the ground and one naturally attempts to clear these. A typical average number of anomalies prelaunch is between 50 and 70.

There appears to be some breakdown in the procedures and discipline in the engineering world, a great deal of it at the subcontractor level. The slide shows two typical examples. Somebody someplace didn't pay enough attention. Fortunately, neither of these two examples happened to result in disaster. The other side of that coin is the story that General Henry told about a conscientious worker finding a chip in the tubing in time.

The TWT problem is a terrible alligator. It's been with us for years. I wish I could say it was going away. It hasn't gone away yet. It's a difficult problem because we are asking travelling wave tubes to do things which they normally don't do in the rest of their industry. We are asking for a very high power and long life combined, a very tough set of things to do. We still don't have competitive production of space quality TWT's. A typical statement in the Readiness Reviews is that the TWT's are marginally acceptable but they are the best available. That's, if anything, a left-handed compliment.

We're not out of the ball bearing problem either, and are likely to continue that as long as we have spinners or spinning platforms or rotating joints. Most of the problem seems to be understanding the usage. The analytic capability we've applied to the ball bearing problem seems to have been a major problem, rather than the materials as such. We just haven't really worked out what the loads are well enough.

Contamination is a problem which continues to plague us. It always will because it involves contamination of some parts of the spacecraft by other parts or by launch vehicles. You can see that there is a new problem which we haven't had to worry much about before, the accelerated outgassing of polymeric systems due to laser attack. There is another one at the bottom which hit us as a surprise, the initially harmless transparent deposits that are around that can become opaque and harmful after long-term exposure to ultraviolet radiation. The basic chemistry changes in those particular deposits. So what we used to think of as an almost "safe contaminant" are, after some years in orbit, proving to be just as bad and sometimes worse than others. The shuttle is going to give us a new set of contamination problems. The shuttle bay is quite different from being inside a protecting shroud which has been carefully environmentally controlled the whole time. The

shuttle bay is not that clean and can present serious problems.

One of the more difficult of the future challenges is the LSI and VLSI complication. We haven't paid too much attention to this yet but I think it's catching up with us fast. Unfortunately, the general thrust of the VLSI buisness is not the same as that needed for space application. The potential of VLSI is great but our space program requirements are very seriously divergent from those of other users particularly in radiation hardness and performance verification. We have previously relied on quality control techniques, precap visual inspection, front end electrical characterization and failure analysis. But these cannot as effectively be applied to LSI; in some cases they can't be applied at all. New techniques have to be developed. Custom designed LSI and VLSI could be very attractive but design verification is then a major problem. Indeed for some VLSI units it's been shown mathematically that complete certification is impossible. Obviously, it's going to be very difficult for somebody who has to certify readiness for launch to have components in the system that he knows cannot be tested in all the modes that the components might see. Unfortunately the industry is going to be at a multibillion dollar level in the mid-80's and will be very resistant to perturbations by special low-volume customers - that's us! If you ask people in that industry what they think, they say well, get some design and manufacture it like mad and hope for the learning curve to sort out the problems - but what if you need quantities of only ten to hundreds? Obviously a much more concerted effort is going to be needed on the LSI, VLSI problem. And for all those happy engineers that say the VLSI is going to do wonders for the space business - yes, it may do wonders, but it's going to be one hell of an alligator as well.

I can't just leave the alligators without bringing up software. I put up only part of the problem here, but those of you that have had to stand around and wait in your program because software was the long pole in the tent know what I mean. That part of our business is not under too good control; we don't understand the management of very large software systems. We do know that we are going to be putting more and more things on spacecraft. We do know that there is a lot of advantage to on-board computers. We are all talking about automated spacecraft; but, go talk to JPL sometime on what happens when this fully automated spacecraft refuses to listen to what you're telling it because it's all automated and knows what it ought to do. Initiation of applications software development before you have the basic tools built has been a classic problem. We talk a lot about the distributed systems on board spacecraft and what the subsystems might do that hasn't been done yet. But if we commit to these systems and don't have the basic data communications and subsystems architectures established, we can be in very severe trouble.

We have a couple of areas that can pose potentially very serious problems. We're starting now into an era where critical raw materials have to be imported; international turbulence is not helping us there! And as General Henry points out in almost every speech that he gives, we have a very narrow industrial base for a space quality hardware. Typical scarcity lists include TWT's, rubidium clocks, electronic piece parts, solar cells, batteries, adhesives and coatings. Every one of these have caused us trouble. Every one of these are produced by a very limited number of companies. We find ourselves in potentially serious trouble because the industries that are involved very often are doing it, if not as a favor to the space business, solely out of patriotism and loyalty to national security. That works fine until a company starts to lose a <u>lot</u> of money. Then management starts to say, "Well, there's a limit to how far we can go in this business.

So, the good news is that we have been doing okay so far; we've got problems that keep staring us in the face that we still haven't fixed yet and it takes gutsy decisions by program managers just to decide to live with the risks. We have new risks that are coming up. The future is going to be tougher than the past.

Two-Year Overview

- LAST MISSION ASSURANCE CONFERENCE CONVENED 25 APRIL 1978
- DURING THE INTERVENING 734 DAYS SPACE DIVISION PROGRAMS HAVE EXPERIENCED
  - NO LAUNCH FAILURES
  - MANY COMPLETELY SUCCESSFUL SPACECRAFT
  - NO CATASTROPHIC ON ORBIT FAILURES, BUT
  - MANY ON ORBIT (and ground test) ANOMALIES, SOME SERIOUS ENOUGH TO AFFECT THE MISSION
- MISSION PERFORMANCE IS CAUSE FOR GUARDED SATISFACTION
- BUT FREQUENT ANOMALIES CONTINUE TO BE TROUBLING

Breakdown in Procedures / Discipline Continues to Plague Top Contractors

- POWER TRANSISTORS INSTALLED BACKWARDS
  - INSTALLED PER DRAWINGS
  - DRAWINGS IN ERROR
- MISSING MYLAR INSULATING SEPARATOR IN ELECTRICAL DRIVE OF THRUSTER VALVE
  - NOT CALLED OUT IN DRAWING

Traveling Wave Tubes (TWTs)

- SPACECRAFT APPLICATIONS IMPOSE STRINGENT REQUIREMENTS ON TWTs
  - HIGH OPERATING FREQUENCY
  - HIGH EFFICIENCY
  - HIGH POWER
  - SEVERE THERMAL AND SHOCK ENVIRONMENT
  - LONG LIFE
- REPETITIVE PRODUCTION OF SPACE QUALITY TWTs HAS NOT BEEN ACHIEVED
  - PROBLEMS IN MATERIAL AND PROCESS CONTROLS DURING FABRICATION
  - DEFICIENCIES IN TESTING DURING BUILDUP AND FINAL ASSEMBLY

Ball Bearings

- MANY SD PROGRAMS HAVE EXPERIENCED BEARING PROBLEMS
  - TEAL RUBY
  - IUS
  - SIRE
  - FLT SAT COM
  - DCSC II AND III
  - OTHERS
- INADEQUATE DESIGN ANALYSIS USUAL CAUSE OF PROBLEMS
  - LOAD CAPACITY DATA IN COMMERCIAL CATALOGS NOT ALWAYS APPLICABLE TO SPACE APPLICATION
  - SOPHISTICATED, BUT AVAILABLE, COMPUTER PROGRAMS FREQUENTLY NOT USED
  - STRUCTURAL FLEXIBILITY OFTEN IGNORED
- UPGRADING OF ANALYTICAL CAPABILITIES (considering structural flexibility) REQUIRED

Contamination

- CONTAMINATION IS BECOMING AN IMPORTANT ELEMENT IN SPACECRAFT LIFETIME
  - IMPACT OF SPACE SHUTTLE
    - CLEANLINESS OF CARGO BAY
    - SHUTTLE THRUSTERS
    - OUTGASSING FROM SHUTTLE
  - NATURAL OUTGASSING OF SPACECRAFT POLYMERIC SYSTEMS OVER LONG LIFETIME
  - ACCELERATED OUTGASSING OF POLYMERIC SYSTEMS DUE TO LASER ATTACK
- SOME OUTGASSING PRODUCTS WILL BE DEPOSITED ON SENSOR AND/OR THERMAL CONTROL SURFACES
  - "OPAQUE" DEPOSITS IMMEDIATELY DEGRADE SYSTEM PERFORMANCE
  - "HARMLESS TRANSPARENT" DEPOSITS MAY BECOME OPAQUE AND HARMFUL AFTER LONG TERM EXPOSURE [illegible] chemistry of deposits)

The LSI / VLSI Complication

- THE POTENTIAL FOR LSI/VLSI APPLICATION TO SPACE PROGRAMS IS OBVIOUSLY GREAT
- SPACE PROGRAM REQUIREMENTS ARE SERIOUSLY DIVERGING FROM THOSE OF OTHER LSI/VLSI USERS IN TERMS OF RADIATION HARDNESS AND PERFORMANCE VERIFICATION (complete functional testing and characterization)
- PREVIOUSLY RELIED UPON QUALITY CONTROL TECHNIQUES SUCH AS PRECAP VISUAL INSPECTION, BURN-IN, ELECTRICAL CHARACTERIZATION AND FAILURE ANALYSIS CANNOT AS EFFECTIVELY BE APPLIED TO LSI. NEW TECHNIQUES MUST BE DEVELOPED
- CUSTOM DESIGNED LSI/VLSI WILL BE VERY ATTRACTIVE TO FUTURE SYSTEMS, HOWEVER, DESIGN VERIFICATION WILL POSE A MAJOR PROBLEM
- THE LSI/VLSI INDUSTRY WILL BE OPERATING AT A MULTIBILLION DOLLAR LEVEL IN THE MID-1980's AND WILL BE VERY RESISTANT TO PERTURBATIONS FROM SPECIAL LOW-VOLUME CUSTOMERS
- OBVIOUSLY, A MUCH MORE CONCERTED EFFORT ON THE PART OF THE GOVERNMENT-AEROSPACE/INDUSTRY COMPLEX WILL BE REQUIRED TO EFFECTIVELY INCORPORATE LSI/VLSI INTO OUR SYSTEMS

Computers / Software (s/w)

- VIRTUE OF ON-BOARD PROGRAMMABLE COMPUTER WITH s/w UPLOAD CAPABILITY CONVINCINGLY DEMONSTRATED (DMSP)
  - PERMITS ADAPTATION OF SPACECRAFT SYSTEMS TO UNFORESEEN CONDITIONS
  - EFFECTIVE EXPLOITATION REQUIRES
    - TROUBLE-FREE SWITCHING BETWEEN REDUNDANT COMPUTERS
    - ADEQUATE GROUND FACILITIES FOR RAPID CHECK-OUT OF s/w TO BE UPLOADED
- INITIATION OF APPLICATIONS SOFTWARE DEVELOPMENT PRIOR TO AVAILABILITY OF MATURE s/w TOOLS STILL A PROBLEM (lack of mature Jovial compiler for DSP Small Processing System (SPS))
- DATA COMMUNICATIONS BETWEEN PROCESSORS IS STILL TROUBLESOME (DSP - SPS)
- PARKINSON'S LAW FOR COMPUTERS ("requirements" will always grow to saturate speed and memory) IS STILL VALID

  (IUS computer, with 4 x speed and 4 x memory of Titan III computer, is "full")

Potential Problem Areas

- CONTINUING AVAILABILITY OF IMPORTED CRITICAL RAW MATERIALS
- NARROW INDUSTRIAL BASE FOR SPACE QUALITY HARDWARE
  - TWTs
  - Rb CLOCKS
  - ELECTRONIC PIECE PARTS
  - SOLAR CELLS
  - BATTERIES
  - ADHESIVES, COATINGS, etc

PAST AND FUTURE CHALLENGES

Gerald E. Lutz
Director of Quality Assurance
Fairchild Space and Electronics Company
(Vice-Chairman, NSIA QRAC)

Two years ago, almost to the day, we concluded the first Mission Assurance Conference. It was an initial attempt to cross discipline lines with a single unique interest and objective. The keypoint was that both Industry and Governmental agencies have a common base to perform a dialogue for a mutual goal - MISSION ASSURANCE.

Major General Howard E. McCormick, past Vice Commander of the Space Division in his 1978 Welcome Address reflected, "This multi-discipline approach - taking a horizontal cut at the entire range of problems that impinge on mission success - marks this as a milestone conference." He further stated "No one realizes more clearly than this assembled group that attaining the quality, reliability and performance levels required for our space and missile system is a tough job - one that requires constant attention and vigilance".

As a result of the recommendations from the 1978 Conference, Space Division benefits have been cited as follows:

- Computer Resources Department established throughout AFSC.
- Acknowledgement of need to balance performance with other incentives - earlier incentive payments.
- Acknowledgement of award fee as a preferred incentive method.
- An "Award Fee Guidebook" prepared and released.
- SAMSO/Industry Committee is preparing a workmanship standard for contractual application.
- Lessons Learned Program implemented.
- Improvements in Independent Readidness Review procedures.
- Aerospace Corporation role explained within contract.
- SAMSO prepared MIL-S-52779 Evaluation Handbook for Software Quality Assurance Program which is in final DOD/Industry coordination cycle.
- Software pamphlets (QA and CADSAT) developed.
- Buying Division QA Manager Training Program being developed for use throughout Air Force Systems Command.
- QA Guidebook for Buying Divisions in final coordination. QA Guidebook for Range and Test Centers has been released.
- Space Parts Working Group expanded for LSI and Hybrids.
- SAMSO encouraging "Pooled-Procurement" of piece parts.
- MIL-STD-1540 under revision.
- Studying realistic burn-in failure rates.

Industry actions were taken in the areas of workmanship standards as they relate to advancing technology, and subcontractor/contractor audits/surveys of small business ventures, especially those associated with new technology. Both actions became joint projects with NSIA and AIA and will be addressed further within workshops this week.

Those who attended the 1978 Conference were asked to complete a result oriented questionnaire. Of the 570 attendees, 70 percent responded to the questions with ranked results as follows:

1. What is highest priority issue bearing on mission success requiring Space Division attention?

   - Improve dialogue with Industry and define priorities better. (If dialogue is improved, most problems can be worked out.

- Improve RFP and SOW including tailoring and application of Specifications and Standards.

- Educate/inform Space Division managers on effective implementation of conference ideas

- Establish more productive incentives

- Improve continuity of Space Division Program Management personnel

- Piece parts

2. What is highest priority issue bearing on mission success requiring Industry attention?

   - Improve motivation

   - Do not buy in

   - Improve design process for Mission Assurance

   - Better communication with sub-contractors

   - Better recognition that space hardware requires tender loving care

   - Better workmanship management

3. The principal value of the conference to me has been:

   - Free and open exchange of ideas and discussion of problems

   - Cross-fertilization of ideas

   - Learning what others are doing and better insight into common problems

   - Better appreciation of Mission Assurance problems and interactions

   - Inspiration

4. The main message I will take back is:

   - There are many positive actions I can take

   - Mission success is a complex mutual problem

   - Space Division is serious (means business) about improving Mission Assurance

5. Should these sessions be continued? If so, what format and frequency?

   - Yes: 100%

   - Frequency: Annual
18 months
6 mos.

   Format: Same format with more workshop time

History has reflected that results can be achieved. Nothing happens if there is no expectation - if we are to be successful, a free and open exchange is essential. Be aware that for these sessions the government is to be treated as a partner instead of a customer - tell each other your concerns. There is an outgoing challenge to each of you to make both good and bad experience sharing happen so that all parties benefit. You are encouraged to express your thoughts throughout the sessions. Attendees of the 1978 Conference left having had a very refreshing experience. We anticipate and expect that you will leave this Conference with the same feelings.

I will now introduce the Chairmen of the "Past and Future Cahllenges of Mission Assurance" panel.

PAST AND FUTURE CHALLENGES OF MISSION ASSURANCE

Panelist: Merland L. Moseson
Director of Flight Assurance
NASA/Goddard Space Flight Center
Greenbelt, MD
April 28, 1980

Introduction

Ladies and Gentlemen, first, I would like to express appreciation on behalf of NASA for being invited to participate in this year's assurance conference. In thinking about what would be most helpful in getting this conference off to a good start in the workshops planned for the rest of the week, I decided to do three things: First, to review the Goddard flight record to see where we have had problems, I'll go back to the beginning in the early 1960's. Second, on an Agency basis, a study of major problems was conducted under the Chairmanship of our Chief Engineer, Walt Williams. These problems were generally experienced on the ground before flight and the results have not previously had much publicity except in an internal briefing by Walt, to the NASA Center Directors and to recap the findings now should be helpful for background at this conference. Third, I simply asked a number of key people from Goddard's discipline organizations what they thought the most prevalent problems were from their viewpoints. After presenting a few viewgraphs to summarize the results of this problem survey, I will then propose three challenges that seem to present themselves from this perspective. I hope that the appropriate workshops will debate these challenges and refine and promote them as recommendations from this conference to solve some of our assurance problems.

The Goddard Flight Record

The first pair of slides illustrates the scope and variety of U.S. and international projects Goddard has managed and flown over the past 20 years and includes examples of spacecraft built by virtually all the major aerospace contractors, as well as those built inhouse by Goddard. On your left for the decade of the 1960's you will see the OAO by Grumman, OGO by TRW, and the origianl OSO series by Ball Brothers among the early scientific satellites. You can also see the earlier application satellites for weather and communications. In this group, we have the TIROS and TOS series by RCA, the Syncom and ATS by Hughes, and NIMBUS by General Electric (GE). There are also several international cooperative satellites shown including ISIS, Alouette with Canada, FR-1 with France, San Marco with Italy, and HEOS with the European Space Research Organization (ESRO).

On your right for the decade of the 1970's, addtional scientific satellites include SAS-C by APL and HCMM and SAGE by Boeing. Also, the Earth observations flights made by GE's Landsat have now started in the applications program together with the last Goddard communications satellite, ATS-6 by Fairchild, and the synchronous orbit weather satellite series by Philco Ford and Hughes. The international programs continued in the ANS program with the Netherlands, CAS with France, the UK-4 and -5 with Great Britain, and Helios with Germany. Finally, shwon on your right is the Delta Launch vehicle by McDonnell Douglas which has flown 151 times and has carried many of these and other spacecraft and now represents a significant experience base. These two illustrations depict a record of significant accomplishments in which we might all take pride and I would expect virtually everyone in this room has either been personally involved or works for a company, agency, or government that has been part of this proud team. We have worked on these missions with seven other countries on individual projects and all of the member countries of ESRO. Also, as a major contributor to this "Team" effort, I would like to remind everyone of the key role by the Department of Defense (DOD). All of these missions were launched by Thor, Atlas, Agena, or Titan boosters--all from the DOD rocket family.

In the next pair of viewgraphs (II-A and II-B) is the Goddard flight record. On your left you see a 94 percent successful score on 131 Goddard spacecraft flown. The asterisk means that this is not based on the official NASA success record which is 97 percent for these missions, because in this conference it seems more appropriate to address major inorbit problems

as failures even though the mission objectives of the spacecraft were achieved Also, on this screen the 91 percent record for 151 Delta's is given and 86 percent for 2,134 sounding rockets. By the ground rules used, we are only scoring spacecraft that have been placed successfully in orbit. In the case of rockets we have had at least one spacecraft success launched by a rocket that is scored a failure because it flew outside the three sigma orbit planned; however, the investigators obtained satisfactory data in the orbit flown. In the case of sounding rockets, the number means that the rocket and payload combinations both worked 86 percent of the time.

On the right screen our learning curve appears to have resulted in a success record gain from 94 to 96 percent between the first and second decades of our experience in space and during a trend toward larger more complex spacecraft. Similarly the Delta batting average has grown from 90 to 94 percent with several block change increases in performance capability. Another difference shown is that we havee a 100 percent success record for the 32 spacecraft which have been at least integrated and tested inhouse versus 93 percent out of house. From my viewpoint this does not mean we are necessarily better than our contractors but when we have had an indepth involvement including the hands-on experience of doing integration and testing in house and varying amounts of in house design, we seem to have been a more effective team "ourselves and industry." The combined understanding achieved in this mode appears to have paid off. Admittedly many of the in house projects were of the smaller explorer class but included several of our larger and more complex spacecraft like OAO-C, OGO-III, OAO-II, ISEE, IUE, and SMM. The real objective of in house effort, however, was to acquire the expertise to be effective or "smart" buyers of the larger and increasing share of our hardware which is designed, built, and tested by industry. I think it is important, however, to keep some level of in house activity in the future simply to maintain competence.

The next scene (III-A and III-B) shows the spacecraft failures we have experienced showing again the 1960's period on the left and the 1970's on the right. Of the seven spacecraft we have categorized as major flight failures from the engineering standpoint, only four were categorized as mission failures by NASA Headquarters, and failed to meet their mission objectives. Even of these, only one, OAO failed to return any data. It is interesting to note that the follow-on OAO is still in orbit, returning high quality data, after about 2,800 days, over 7.7 years in orbit. This is OAO-C, also called OAO-3 and Copernicus which was launched August 21, 1972. Ironically we often have real economic problems with being too successful. This is because when scientific missions are planned, they are usually budgeted for a much shorter life time in operations and with several of them proving to have considerably more longevity in orbit, their operations become very hard to support financially for their full lifespan.

Returning to the viewgraphs displayed, of the seven failures, three were due to early difficulties with three-axis stabilization systems. The four others resulted from power problems.

In this flight experience, even when our spacecraft worked well, our studies indicate that the typical mission experiences about 8 or 10 anomalies during the first 3 years in orbit. Of these, almost half occur in the instruments or experiments, and the rest are distributed among the major subsystems as follows: C&DH--20 percent, S&C--14 percent, Power--9percent, other--10 percent. These percentages have remained constant over the years. The vast majorities of these anomalies, about 90 percent, are trivial and have no real effect on the mission.

Taken collectively, all engineering disciplines and nearly all our contractors appear to have been involved in our failures during ground and in orbit; Murphy travels everywhere.

Agencywide Problem Survey

Now having shown you briefly the Goddard experience, I would like to go on to step two and take a look from the NASA as an Agency perspective based on the

findings of a Failure/Incident Assessment Panel which was convened in the Fall of 1978 at the request of the Deputy Administrator to undertake an Agencywide quick-look examination to determine if failures and incidents were part of a pattern.

For the purposes of the panel, a failure was defined as "the inability to perform a specified, or normal function"; and an incident, as "any unexpected occurence." The panel, which was chaired by the Chief Engineer of NASA and included representatives from each field center as well as NASA Headquarters, reviewed failures and incidents experienced within NASA flight projects principally over the previous 12 months to identify underlying factors and determine if correctable patterns existed.

A total of 15 projects were examined, as follows:

JPL:	Seasat, Voyager
Ames:	Pioneer-Venus, TRRA, RSRA, QSRA
GSFC:	Landsat, IUE, HCMM, ISEE
Johnson:	Orbiter
MSFC:	Solid Rocket Booster, External Tank, Space Shuttle Main Engine, HEAO

In the next pair of viewgraphs (IV-A and IV-B) is a quick capsule of the results from this activity. On the left in bar graph form you can see that nearly two-thirds of our problems relate to design with the heavier share of design difficulties stemming from analysis deficiencies versus improper execution by making errors or using substandard practices. The other one-third of problems resulted from test deficiencies--14 percent and qulity control weaknesses--21 percent. Further breakdown within these categories is provided on your right screen and again we see trouble scattered across all disciplines.

Most of these failures and incidents occured during ground operations in preparation for flight. Of a total of 70, 5 were ascribed to failures or incidents which are unavoidable in development type work. The others were categorized as shown in the viewgraphs. It was concluded that the problems were widely distributed, and had no pattern.

The general findings in the Fall of 1978 were that the occurrence of failures or incidents is no greater than in the past, but that they are occurring later in the development cycle due to reduction in development testing and component level testing. There were also problems caused by errors in estimating levels of technical readiness, and lack of control over fixed-price contractors.

The field centers felt they were handicapped by the incremental and unpredictable annual funding cycle, hampering their ability to plan total projects intelligently. Funding constraints result in the deletion of analysis and low-level testing, resulting in paying the price later in high-impact test failures. Both QC and testing are tempting areas to cut to meet cost and schedule goals.

Some Discipline Specialist Opinions

For the third and last approach to identifying weaknesses in our assurance program, I will summarize the results of soliciting opinions from Goddard's specialist personnel in the disciplines of design, piece parts, materials, performance verification and quality control in the next two viewgraphs (V-A and V-B). Under those discipline headings are distilled quotations from persons responding.

Design Engineers

--There is no apparent concentration or pattern of design problems in any specific area, nor does the relative frequency of design problems appear to be changing.

--True systems engineering is not being effectively prosecuted. System engineering is pursued as a low-level effort, applied primarily in the early stage of a program. Systems are treated essentially as an accumulation of subsystems. The number of "cracks" increases as the number of subsystem contractors increases.

Parts Engineers

--Parts availability problems occur because functional discipline either does not exist or is not brought in on timely or adequate basis. Significant

problems occured in the past 5 years at many of our contractors.

--Economic feasibility problem for suppliers in view of low volume relative to commercial parts.

--Rescreening has been found necessary due to evidence of part not being properly processed; e.g., LM108 particle problems.

--Two parts--(a) Aerospace contractors are manufacturing hybrid microcircuits in many instances without knowing or utilizing the R&QA methods found necessary by established microcircuit suppliers.

--(b) Increasingly complex VSLI microcircuits and more complex hybrids call for the development of new R&QA techniques.

Materials Specialists

--Contractors have de-emphasized the use of materials specialists, causing oversights by personnel not familiar with material properties.

--Example: Reynolds aluminum problem. Process was not properly controlled or monitored.

--Example: B-nut sleeve cracking problem on Atlas AC-49 attributed to improper material selection, heat treatment, and faulty inspection that failed to uncover the degraded material.

--Example: The recent problem with Shuttle Orbiter main engine welds was attributed to intermixing two different types of welding rods. The distribution, receiving, and inspection controls applied apparently lacked an appreciation of this important material control problem.

Performance Verification Specialists

--Traditional Goddard test policy historically has emphasized testing at the system level under the philosophy that it exercises all the interfaces and provides a more accurate simulation. System level testing is less feasible and more costly as payload size increases. We must be certain changes to this policy now taking place do not degrade our mission reliability record.

--The Navy now requires routine confidence testing on many contracts. Recent problems with conductive particles and poor workmanship on complex components suggest we also should consider this policy. But what should the requirements be and what are the cost benefit tradeoffs vis-a-vis our current policies?

--Past policy assumed high criticality for every mission. Shuttle reflight capability reduces requirements for noncritical missions. Our problem is to concretely adjust test requirements to reflect various levels of mission criticality to optimize cost effectiveness.

Quality Control Engineers

--Assurance requirements are often underestimated initially and/or cut back as cost and schedule problems develop.

--Important to apply QC engineering early in the negotiation phase for long lead and/or non-standard items such as hybrids, microprocessors, or radiation-hardened devices.

Challenges

Now I will offer the three challenges that I think are suggested from the problems we have experienced at Goddard, from our Agencywide survey, and from assurance specialist opinions. The first one will seem sort of motherhood-like but fits the general objective of this conference and this challenge is presented specifically to place emphasis on cost effectiveness and is shown in viewgraph VI.

I believe on a bottom line basis our technical reputation enjoys a better rating than our ability to control costs. More importantly, I believe we as taxpayers have incurred avoidable expense and if given a more effective assurance program both reliability and cost control could improve. Let's get some good ideas developed in the workshops of this conference.

My second challenge in the next viewgraph (VII) is not an original idea with me as I think other Centers like MSFC and Ames may be ahead of us within NASA in utilizing the incentive approach and I really don't know how we compare with DOD programs. Front end incentives for assurance are very attractive to me because properly applied, they can make it more inviting for our contractors to apply the needed discipline skill groups in parts, materials, and quality control early in the program. It appears to me they can also help get Failure Mode Effects Criticality Analysis (FMECA) more ingrained into the design activity and promote more effective test planning and better assessment of the hardware adopted from other programs. The other big appeal about incentives is that recognizing that we are a big team and with all aerospace companies being more motivated on front end work emphasis there seems to be an attractive potential. If in the workshops you will develop good specific ideas along these lines, I will help get them implemented.

My last challenge is much narrower in scope and is basically the question shown in the next viewgraph (VIII). "Should we institute confidence testing as a routine aspect of the testing portion of our assurance programs?"

Confidence testing, or environmental screening refers to the application of environmental stresses to electronic parts, components, or subsystem for the purpose of detecting defects in manufacturing or workmanship. The tests are most effective with electrical activation and monitoring during test. The types, levels, and durations of tests are selected on the basis of empirical or other evidence of effectiveness, without regard for the in-service environment, except that the tests should not be so severe as to reduce the operational life of the tested item. The most effective screens are generally conceded to be random vibration and thermal cycling.

Goddard policy has traditionally required acceptance testing at the component and system level as well as qualification testing for prototype or protoflight equipment. The levels and durations have been based on measured or predicted flight environments, which are generally more severe than the levels usually recommended for confidence testing, although usually shorter in duration.

Only the system level tests have been mandatory, however, and practice on the subsystem or component level has varied widely from project to project. Although the success of this policy is attested to by the flight record, the increasing complexity of state-of-the-art electronics and the ever decreasing size of its constituent element increase the probabilty of defects in electronics equipment while at the same time, decreasing the prospects of finding those defects by traditional inspection and bench check techniques.

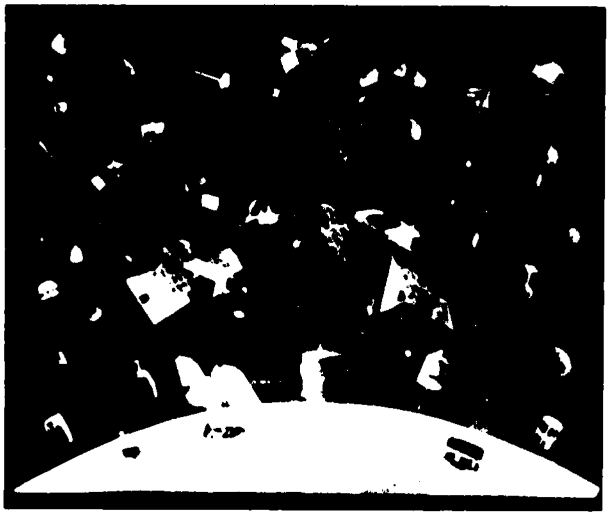
We know it will cost money to implement confidence testing but will it not save more money by avoiding failures late in the build up?

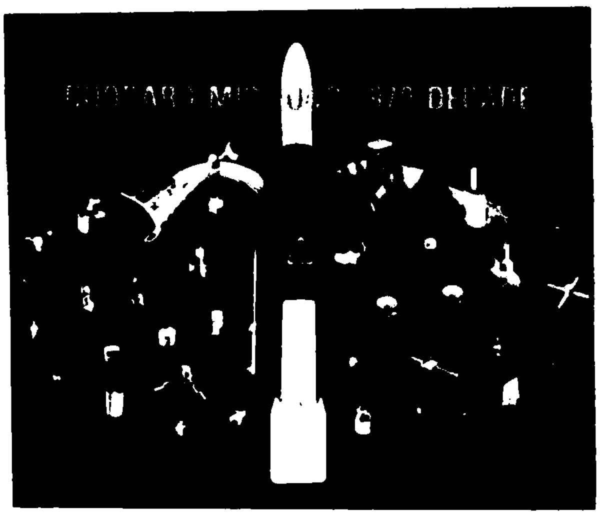
As background for considering this question, we can say historically, NASA instituted a highly successful screening program for the Apollo mission which consisted of a shaped random vibration test and a thermal cycling test. The results of these tests were widely reported in the literature (e.g., Simpkinson: Testing to Insure Mission Success, "Aeronautics and Astronautics," March 1970)

The Navy has now adopted a similar program (Navy Manufacturing Screening Program, NAVMAT P-9492, Author: Willis Willoughby, 703-692-9058 for copies). The temperature cycling requirements were derived from a Martin-Marietta report for NASA on industry experience in assuring long-life hardware. The random vibration requirements were based on a Grumman study summarizing their experience in the Apollo program.

A great deal of research and investigation is currently taking place in the field of screening. Most notably, the Institute of Environmental Sciences has established a national program on Environmental Screening of Electronic Hardware. A Steering Committee, consisting of industry wide and government representation, has been appointed and has already held at least two meeting. The committee had hoped to document interim screening guidelines by June of this year.

Again, I would like suggestions to result from the workshops of this conference. Now, it's my pleasure to introduce the next and final panelist: Dr. Eberhardt Rechtin, President, Aerospace Corporation.





GODDARD FLIGHT RECORD

	NUMBER	% SUCCESSFUL
● SPACECRAFT PLACED IN ORBIT	131	94*
● DELTA LAUNCHES	151	91
● SOUNDING ROCKET LAUNCHES	2134	86

*97% OFFICIAL SUCCESSES

GSFC FLIGHT RECORD

	LAUNCHED	% SUCCESSFUL
● SPACECRAFT		
BY DECADE		
1960'S : LAUNCHES	81	94
1970'S : LAUNCHES	50*	96
IN-HOUSE VS. OUT-OF-HOUSE		
INTEGRATED & TESTED IN-HOUSE	32*	100
INTEGRATED & TESTED OUT-OF-HOUSE	99	93
● DELTA LAUNCH VEHICLE		
1960'S LAUNCHES	73	90
1970'S LAUNCHES	78*	94

*INCLUDES ONE 1980 LAUNCH

GODDARD'S MAJOR FLIGHT FAILURES IN THE 1960'S

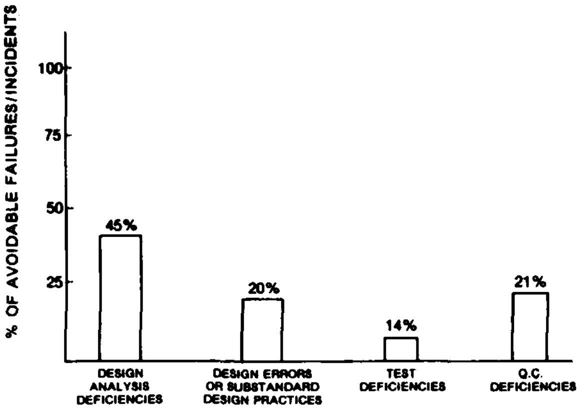
S/C & LAUNCH DATE	PROBLEM	REMARKS
NIMBUS I 8/64	SOLAR ARRAY DRIVE DESIGN FAILURE	ORBIT LIFE—1 MONTH LIMITED DATA RETURN MISSION DECLARED SUCCESSFUL BY NASA HQ
OGO A 9/64	3 AXES STABILIZATION FAILURE	ORBITAL LIFE—62 MONTHS HIGH EXPERIMENT DATA RETURN
OGO C 10/65	SCANNERS SENSOR RESPONDED TO CLOUDS	ORBITAL LIFE—28 MONTHS HIGH EXPERIMENT DATA RETURN
OAO 1 4/66	POWER SYSTEM FAILURE	ORBITAL LIFE—0 NO DATA RETURN
ATS-V 8/69	FLAT SPIN IN WRONG DIRECTION	ORBITAL LIFE—117 MONTHS S/C SYSTEMS OPERATIVE AND HIGH EXPERIMENT DATA RETURN

GODDARD'S MAJOR FLIGHT FAILURES IN THE 1970'S

S/C & LAUNCH DATE	PROBLEM	REMARKS
SAS-B 11/72	FAILURE OF LOW VOLTAGE POWER SUPPLY IN EXPERIMENT	ORBIT LIFE—6½ MONTHS MISSION DECLARED SUCCESSFUL BY NASA HEADQUARTERS
AE-D 10/75	LOST SOLAR ARRAY POWER — FAILURE IN POWER SUPPLY ELECTRONICS	ORBIT LIFE—5 MONTHS MISSION DECLARED SUCCESSFUL BY NASA HEADQUARTERS

PROPORTION OF FAILURES/INCIDENTS IN EACH CATEGORY

(INTERNAL NASA STUDY OF 15 PROJECTS: FALL 1978)



CATEGORIES OF UNDERLYING FACTORS

- DESIGN ANALYSIS DEFICIENCIES ____ 29
  - THERMAL 2
  - DYNAMIC 9
  - STATIC STRUCTURAL 2
  - TOLERANCE BUILD-UP 4
  - SYSTEM INTEGRATION ANALYSIS 7
    - INTERFACE COMPATIBILITY
    - HARDWARE/SOFTWARE COMPATIBILITY
    - TIMING ANALYSIS
  - FAILURE MODE AND EFFECTS ANALYSIS 3
  - *"OFF THE SHELF" SUITABILITY ANALYSIS* 2
- DESIGN ERRORS OR USE OF SUBSTANDARD (FOR SPACE) DESIGN PRACTICES ____ 13
  - MATERIALS OR DESIGN MISAPPLICATIONS
  - MANUFACTURABILITY, INSPECTABILITY, OR SERVICEABILITY NEGLECTED
  - INCOMPLETE SPECIFICATION OF REQUIREMENTS
- TEST DEFICIENCIES ____ 9
  - POOR TEST DESIGN 4
  - RELAXED DISCIPLINE FOR DEVELOPMENT TESTING 4
  - POOR PROCEDURES/DISCIPLINE FOR PROTOFLIGHT TEST 1
- QUALITY CONTROL DEFICIENCIES ____ 14
- UNAVOIDABLE IN DEVELOPMENT TYPE WORK ____ 5

70

ISSUES

- DESIGN
  - NO SPECIFIC TRENDS IN NATURE OF DESIGN PROBLEMS
  - SYSTEM ENGINEERING EFFECTIVENESS APPEARS TO BE WEAKENED AS A NUMBER OF PARTICIPATING ORGANIZATIONS INCREASE
- PARTS
  - MORE PARTICIPATION OF THE CONTRACTORS PARTS ENGINEERING FUNCTIONAL ORGANIZATION
  - SHORTAGE OF SUPPLY SOURCES FOR HIGH QUALITY STANDARD PARTS—ESPECIALLY SEMICONDUCTORS AND MICROCIRCUITS
  - NEED MORE RIGOROUS QUALITY ASSURANCE CONTROL FOR STANDARD PARTS
  - ASSURANCE CONTROL TECHNIQUES NOT KEEPING UP WITH HARDWARE TECHNOLOGY

ISSUES

- MATERIALS
  - DESIGNERS FAIL TO USE MATERIALS FUNCTIONAL SKILLS
  - SLIP-UPS IN PROCESS CONTROL
  - UNNECESSARY USE OF STRESS-CORROSION-SENSITIVE MATERIALS
  - FAULTS IN INVENTORY CONTROL
- PERFORMANCE VERIFICATION
  - HOW MUCH LESS "PAYLOAD LEVEL" TESTING IS VIABLE?
  - SHOULD WE DO MORE CONFIDENCE TESTING?
  - HOW TO STRATIFY REQUIREMENTS AS A FUNCTION OF MISSION CRITICALITY
- QUALITY
  - PREVENTING ASSURANCE PROGRAM FROM BEING COMPROMISED BY RESOURCE CONSTRAINTS
  - GETTING ADEQUATE ATTENTION TO LONG-LEAD PROCUREMENT ITEMS

CHALLENGE

IDENTIFY AND PROMOTE ASSURANCE TECHNIQUES THAT WILL IMPROVE COST EFFECTIVENESS AND RELIABILITY.

CHALLENGE

- HOW MANY OF OUR ASSURANCE PROBLEMS COULD BE ALLEVIATED BY APPROPRIATE FRONT-END INCENTIVES IN THE CONTRACTING SYSTEM?

CHALLENGE

- SHOULD WE INSTITUTE CONFIDENCE TESTING AS A ROUTINE PHASE OF THE ASSURANCE PROGRAM?

Thomas A. Meaker

Ladies and Gentlemen, it is always a pleasure to visit the UNITED STATES OF AMERICA and from the experience of attending the last MISSION ASSURANCE CONFERENCE and WORKSHOP it is a particular pleasure to be here again.

In the tradition of this MISSION ASSURANCE CONFERENCE I am going to speak very frankly and hope this is the intention of everybody for the next four days.

I believe we must continuously analyse our performance i.e. our achieved results against the original requirements and strategies - and the points I am making today are based on just such investigations - particularly - concerning the policy aspects.

Let us in any case, DEFINE the MISSION EARLY and TELL everyone involved WHAT IT IS ABOUT.

At this time the European Space Agency is primarily involved in five main activities:

1) An application satellite programme.

2) The development of space lab for shuttle applications.

3) A scientific satellite programme- part of it in league with NASA.

4) The Ariane Launch Vehicle and the Guyana Launch Site.

5) An supporting research and development programme.

For the purpose of my contribution to this conference, I would like to state that, I consider one of the greatest impediments that prevents us from obtaining higher mission assurance, within the decreasing funding and time available, are inadequate methods of management and, in particular, relating to the management of critical aspects.

In a world of increasing complexity where the prediction of the future is becoming increasingly inaccurate, and political economics are increasingly dependent on, and orientated to, a "consumer-product structured-industry", the task of evolving a specialist management system is very difficult - but absolutely necessary.

In terms of "the bottom line return", we are in a minority section of the industry.

In the western world there is, on average more than one major conference on specialist subjects per day. The only "realistic," conference that I am aware of, where all disciplines can be discussed at one time is this one. Hence I would encourage all members of this conference to keep the following issue and challenge always in their peripheral vision:

ISSUE: To improve management with, existing resources, risk estimators etc. To achieve higher mission assurance.

CHALLENGE: To better define the control of critical aspects; be aware of technique available and their limitations.

It is worthwhile noting that our Data Centers are saturated with techniques designed, and often "guaranteed", to prevent failures occuring - and yet, often with agonizing results, they still occur. Not only do failures still occur, but they often occur where it really hurts, in ORBIT .... or other operations!

For a typical geostationary telecommunication satellite, the time and resources spent on problem solving prior to launch is costing many millions of dollars; this does not include programme delays, etc., but refers only to the identification and processing of the non-conformance data, particularly for those events that catch us unawares.

There is clearly something wrong with the way we handle our business.

My first point is that whatever our business, we must have a policy, a policy that clearly integrates all necessary disciplines at the correct point in time, and in my opinion, requires that everything should be related to the hardware that actually flies.

My second point is that customer and contractor must clearly understand and

agree the mission assurance effects of RFP clauses and bid commitments BEFORE the contract is signed. For example, the meaning, to customer and contractor, of the standard RFP clause requiring "visibility and decision making involvement" can be debated almost ad infinitum. It is difficult to conceive a more ambiguous statement and yet that statement alone can cost a great deal of "wasted" money by improper application and can in fact, reduce mission assurance. We must think in terms of the contribution these clauses make to mission assurance, the positive influence they have on hardware and software adequacy to meet the mission requirements. We must try to avoid contractual clauses that on the one hand constitute self effacement and on the other hand, actually prevent the implementation of efficient policies management systems.

It is my belief that a bid must clearly demonstrate how the management organization intends to, practically, function in an invironment where a simplistic systematic problem solving system cannot, by definition handle the critical non-systematic problems that always occur. One aspect in which we are often delinquent is having system PA, and Project Managers who are not adequatly qualified and lack system engineering experience and management training, and are NOW AWARE of the value of techniques which are available. Another aspect which receives, in my opinion, insufficient attention at the design stage, is hardware engineering. "Is it being put together properly?" How critical is workmanship and does it have a different criticality in different areas?

My discussion so far has mentioned some of the problems and constraints we are all faced with - most of them obvious; BUT, what is our most critical and valuable resource - a resource that contains the following terms:

It is ... polarized

variable

indispensable

unpredictable

logical

irrational

emotional

unreliable

dependable,

and contains extremely complex interfaces.

That resource, gentlemen, is US. It is the resource we know least about and yet we must also classify, integrate, schedule, develop, motivate and be managed by that resource in order to achieve a high mission assurance of our product: the expert whose views are ignored first time, probably won't try to contribute effectively in the second round; A world of PHD'S, and managers will not give us mission assurance. Personal experience, therefore, is also a critical resource.

So much for talk and suggestion. At the European Space Agency, I have attempted to implement some of the very good ideas from the U.S. Aerospace and elsewhere. The implementation which is still being developed consists of the production, in the bid phase, of a critically manual; a blank page of which is on the screen now; The manual constitutes a management tool, by which resources, by type can be defined and deployed, according to equipment/mission criticality and therefore problem occurance. It should be noted that all areas of expertise are involved. A "design of test" (i.e. verification of the test plans by comparison with the FMECA) is involved. Priority and phasing of inspection of hardware is determined as a function of the criticality of the design, local technology, workmanship (solder joint in the limit) etc. to mission success.*

*Following a number of requests, I have included a more detailed explanation of the criticality management system as an appendix to this paper.

From my experience, management must develop a clear policy and criticality assessment tools. The tools must be dynamic, the management flexible but the application of the policy quite rigid. Scarcity is criticality and must be considered in the endeavor to improve mission assurance. As project time elapses, an Einsteinian $E = MC2$ relationship seems to develop with respect to resources needed to solve late problem occurances i.e., resources needed

to solve late problem occurances i.e.; resources needed astronomically expand the later the problem occurs or is identified. In many cases these events can cause corporate reactions which can not only reduce mission assurance to an unacceptably low level, but can phase us out of the business. Let us therefore realize that the occurance of a particular problem at different points in a programme, can change its criticality and impact very significantly.

In conclusion, I consider that the proper application of product assurance standards requires informed, innovative, and flexible thinking. I even would apply this consideration to the qualification of technology where I believe, we in the space industry, must look "wide-band" at industrial efforts in order to use a maximum amount of information without duplication.

I believe that we have done a good job, when we have achieved our mission assurance targets, then we deserve a pat on the back. At this point in time, at the commencement of this very worthwhile conference, which is so dependent on all our efforts to be successful, let us not pat ourselves on the back until the work is done.

I truly compliment and congratulate the initiators and organizers of this event. They say it takes a genius to spot the obvious, now that it has been conceived, this conference clearly is an obvious requirement to us all.

Thank you.

APPENDIX

CRITICALITY MONITORING SYSTEM

In order to try and assess the criticality of various hardware elements in a spacecraft programme and to incorporate into that criticality assessment the results of the analyses and the inspection activities, a monitoring manual was constructed with a rating system against the various criteria. The criteria covered the manufacturing and hardware history of the particular company involved, the design and in particular the design reliability; The use of parts materials and processes, the non-conformance history of the particular equipment, parts information in general, and also CADM information. The manual consists of one page per equipment type and covers every equipment type on a particular satellite. A page of Issue 1 of the manual is shown attached to this paper and it will be noted that against four of the criteria a rating value is given; the rating constitutes a selection of a number between 1 and 3 with the most critical rating being at the lowest number, i.e. the most critical elements have a rating of 1. The rating is applied by the expert concerned after the expert has been instructed on the use of the manual and the scope of the rating system by the Product Assurance Manager concerned. It will be seen that an overall rating for the equipment, which is arrived at by arithmetically averaging of the individual ratings, is contained on each page.

You should also be noted that there is an area for "qualified remarks" i.e. to cover areas which are not specifically covered or which are not covered in sufficient detail by the other windows of the page. From an analysis of the individual rating assessment, equipment specific monitoring requirements for ESA representatives are written down at the bottom of each sheet. By this method a particular part of an equipment can be identified as being of particular criticality and this therefore would be given a specific inspection point.

Where it is considered that the design is more critical than the hardware then the design aspect would receive priority attention. The overall intent is to enable an engineer or manager to have rapid visibility of the most critical elements of the spacecraft and in addition to be informed of where and why those particular areas are critical.

Following on this it is possible for management to identify particular critical areas and to schedule, a priori, resources to cover those needs. In practice the most critical elements within the manual are brought together and are monitored prior to the monitoring of other areas.

It has to be noticed that the manual must be maintained in an updated condition and that the priorities for particular expertise and a particular monitoring application may change as the project advances.

If any more detailed information is required on this system then the author would be pleased to discuss the subject matter on a case by case basis.

EQUIPMENT/BOX

CRITERIA		SUMMARY OF RATING APPLIED	RATING
MANUFACTURING AUDIT HISTORY	COMPANY		
DESIGN RELIABILITY	FAILURE RATE		
MATERIALS AND PROCESSES CRITICALITY			
NON-CONFORMANCE HISTORY			
PARTS INFORMATION			
CADM INFORMATION			
OVERALL RATING	QUALIFYING REMARKS		

SPECIFIC MONITORING REQUIREMENTS FOR ESA REPRESENTATIVES

WORKSHOP A
MANAGEMENT OF PROGRAMS – PUTTING IT ALL TOGETHER

Chairmen:

LT. Col. Robert Baumgartner
Space Division

Charles Hall
Project Manager
ARC-NASA

Martin Titland
Vice President, Space Programs
Fairchild Space & Electronics Co.

Coordinators:

Dean Linstrom, HAC
Jerry Lutz, FSEC

WORKSHOP PRESENTATIONS

Government Roles and Responsibilities	Howard Wright, Nasa-Langley
Cost Credibility in a Resource Limited Competitive Environment	James D. Cloud, HAC
Risk Management	Don Hurta, War College
Shuttle Payload Integration Management	Leonard Nichlson
Future Challenges for Reuseable Space Systems	Ben Wier, G.D.

Discussion Groups

Risk Management	Don Hurta
Planning and Control for Cost and Schedule	TBD
Industry Responsibility - Profit, Risks, Incentives and Contracting Forms	James D. Cloud
Payload Integration Management in the Shuttle Era	Ben Wier
Staffing - Time Phase, Selection of Key Personnel, Motivation	Bill Miner
Roles and Responsibilities, Quality and Quantity, of Government Involvement in Assuring Contractual/Mission Performance	Howard Wright

GOVERNMENT ROLES AND RESPONSIBILITIES, QUANTITY AND QUALITY, OF GOVERNMENT INVOLVEMENT IN ASSURING CONTRACTUAL/MISSION PERFORMANCE

Howard T. Wright
Director for Projects
NASA-Langley Research Center

The success of any mission that involves a complex assembly of hardware and software is usually totally dependent upon <u>all</u> of the elements of the system to perform as desired. There is therefore no one part of a program that can be considered more important than another because each is like a link in a chain and all must be present if the chain is to perform. The roles and responsibilities of the government in the management and acquisition of a system has varied significantly in the past. In some cases the government has taken on the responsibility for the integration of the efforts of many contractors and has played a significant role in the total program management. With this approach the government is intimately involved on a daily basis and must be prepared to adequately staff a project office with qualified people in order to provide the necessary direction to the many contractors involved. In this type of program management the government is clearly responsible for establishing the fundamental requirements for such things as subcontract type, interface control, configuration control, performance specifications, quality assurance policy, etc. Recently there has been a trend toward less direct government involvement by contracting with a prime "system integration" contractor and requiring the contractor to deliver an end product to meet a performance specification with very little government involvement along the way. Either approach can be successful, however, there are fundamental ingredients to mission assurance that must be present for success and the government must be reponsible either in a very direct way if the first approach is used or the government must be responsible for the selection of a prime system contactor that has the experience and the necessary ingredients for success. In any event there must clearly be someone in charge of the program and that someone has the responsibility for the many management decisions that will affect the course of the program. The following comments are based on the author's experience on programs in which the government has played a significant role in the management of the project. It is believed that the same general comments would apply to the "Systems Integration" contractor if the government elects to contract for that service.

1. <u>Balanced Program</u>. - The success of any program is dependent upon the proper balance between the forces that would influence the technical performance, the cost and the schedule accomplishment. One successful project manager always referred to these three items as the three legs on the milk stool, where clearly the utility of the stool is dependent upon each of the three legs to the same extent. The government's responsibility in establishing a contract must clearly include a thorough knowledge and understanding of the costs involved and of the schedule performance. All too often a program is established on the basis of technical requirements and arbitrary or unrealistic cost and schedule requirements are applied. When unrealistic technical performance requirements, cost requirements or schedule requirements are established by the government, excessive pressures are created on the subcontractors, and the quality of the end product is bound to suffer as a result. The government's responsibility for assuring a balanced program does not stop at the issuance of a contract, but rather requires continual vigilance throughout the life of the program with many changes and decisions being made to be sure that there is always the proper balance between these three essential elements of any successful program.

2. <u>Selecting the People</u>. - One of the first responsibilities that the government has in establishing a new program is to select the people who are to be responsible for the management of the program. It is important that this selection be done on the basis of experience and demonstrated capability. All too often people are selected on the basis of availability, and thus a program may suffer due to lack of the necessary experience and know-how

to accomplish the objectives of the program. The government's program for merit promotion goes a long way toward the solution to this problem; however, there is clearly a need for greater mobility for people within the government. Because of variations in cost of living between different parts of the country, it is currently very difficult to staff some government positions with the most qualified people. For those cases where it is not possible to obtain the level of experience or expertise required to fulfill a job assignment, it is the responsibility of the government to provide adequate training for the individuals who are assigned to the program.

3. Cost Estimating and Management. - An extremely important part of the government's responsibility in establishing a new program is to determine a realistic cost for the program. A healthy contractor who is making a profit is a far better and more responsive contractor than one who has overrun a fixed price contract and is spending his own money to meet the program objectives. It is the government's responsibility to take those steps necessary to insure that all contractors have an opportunity to make a reasonable profit. This responsibility is a continuing one, and cost management throughout the life of the program is important if the government is to be successful. Cost offset programs descope options, performance relaxation, etc., are some of the options available to the government, and all must be under continuous review throughout the life of the program.

4. Contracts. - The government has a responsibility to determine the type of contract to meet the specific needs of a program. Contracts must be written in such a way that contractors are required to provide the government with the information necessary to properly assess the contractor's performance throughout the life of the contract. Different types of contracts may be appropriate for different kinds of programs, and the government is responsible for the selection of the type of contract that best satisfies the program needs.

5. Communications. - Some programs in the past, particularly large ones, have suffered significantly due to a lack of adequate communication between various participating groups. The government is responsible for the establishment of a communications system that will provide the opportunity for problems at all levels of the organization to be heard at the proper level, and when decisions are made the communications system must communicate with all of the parties affected by the decision with a minimum of delay. The government is responsible for the establishment of specific review meetings at various stages of the program. This responsibility includes assurance that the proper people are in attendance at review meetings, that formal documentation is established for all action items, and that decisions on all action items are made in a timely fashion and formally communicated to all parties.

6. Test Philosophy. - The government is responsible for the establishment of a test philosophy to meet the requirements of the program. It is easy to say that the system hardware must be demonstrated to perform as required in the environment in which it is to be used, and that a test program be devised to qualify the hardware for that environment. In many cases it is difficult to specify the total environment for the end use of the hardware since many elements of the environment may not be well known. It is, nevertheless, the government's responsibility to determine what the environment will be to the best of its ability and establish a test philosophy that will insure the performance of the hardware in the real environment.

7. Failure Analysis. - One area in which many programs have had difficulty has been the establishment of an adequate failure analysis program for the hardware being developed. The government's responsibility may be to establish the basic philosophy for failure analysis, or in many cases, it may be necessary for the government to actually conduct failure analysis for those contractors who may be unable to adequately conduct their own failure analysis. It is important for the government to establish a baseline hardware configuration and carefully track all failures from an established

point in time to be sure that adequate corrective action has been taken to preclude a recurrence of the same failure. Although this sounds very simple and straightforward, it is remarkable how many programs have existed without the necessary discipline in a failure reporting and analysis program.

8. Providing Help. - The government has a responsibility and a unique capability to provide "help" to contractors who are working on their program. Many contractors have limitations in certain areas and the government, because of its size and diversity, has a unique ability to provide assistance in almost any technical or managerial area.

9. Advisory Group. - For large and complex programs, the government has a responsibility to assemble and manage advisory groups that have unique expertise in the various elements of a program. Very often such advisory groups can be small and need to meet infrequently at specific times in the program as designated by the program manager. In other cases it may be necessary to establish working groups of people to concentrate on a problem area for a significant period of time. In any event, it is the government's responsibility to see to it that the proper expertise is applied to any difficulties that may arise during the course of the program.

The above responsibilities and others will be discussed in the workshop titled "Government Roles and Responsibilities, Quantity and Quality, of Government Involvement in Assuring Contractual/ Mission Performance."

TEST PHILOSOPHY

- ESTABLISH ENVIRONMENTAL TEST PROGRAM
- PROVIDE FOR COMBINED ENVIRONMENTAL TEST WHEN PRACTICAL
- REQUIRE SYSTEM TEST IN REAL ENVIRONMENT

BASIC MANAGEMENT APPROACH

- EXTENSIVE GOVERNMENT INVOLVEMENT
  - LARGE PROGRAM OFFICE
  - DAILY INVOLVEMENT IN DETAILS
  - INVOLVEMENT IN ALL POLICY MATTERS
  - DETAILED INVOLVEMENT IN ALL SPECIFICATIONS
- SYSTEMS INTEGRATION CONTRACTOR
  - MINIMUM GOVERNMENT INVOLVEMENT
  - DEPENDENT ON SUBCONTRACTOR
  - PERFORMANCE SPECIFICATION

BALANCED PROGRAM

- TECHNICAL
  - PERFORMANCE TRADE STUDIES
  - GET THE EXPERT
  - MUST RECOGNIZE COST AND SCHEDULE
- COST
  - GET REALISTIC COST ESTIMATES
  - TRACK AND MANAGE ALL RESOURCES
- SCHEDULE
  - PLAN A REALISTIC SCHEDULE
  - BE FLEXIBLE -- AVOID SCHEDULE PRESSURES

FAILURE ANALYSIS

- ESTABLISH FAILURE REPORTING AND CLOSEOUT PROCEDURES
- HELP CONTRACTORS TO DO FAILURE ANALYSIS
- GET A PARTS AND/OR MATERIALS EXPERT

SELECTING THE PEOPLE

- LOOK FOR EXPERIENCE
- PROVIDE FOR TRAINING
- AVOID ACCEPTING SOMEONE ON THE BASIS OF AVAILABILITY
- LOOK FOR WAYS TO OVERCOME OBSTACLES DURING SELECTION OF PEOPLE
- LEARN HOW TO MOTIVATE PEOPLE
- SHARED EXPERIENCE

COST ESTIMATING AND MANAGEMENT

- USE AVAILABLE COST ESTIMATING PROCEDURES
- SPECIFY COST REPORTING TO DESIRED WBS
- PREPARE COST OFFSET AND DESCOPE PLANS
- MANAGE RESERVES
- CLEAR ASSIGNMENT OF RESPONSIBILITY AND AUTHORITY -- ACCOUNTABILITY
- THE CONTRACTOR SHOULD MAKE A REASONABLE PROFIT

PROVIDING HELP

- GOVERNMENT HAS LARGE RESOURCE IN TECHNICAL EXPERTISE

USE IT

- LOOK FOR CONTRACTOR WEAKNESS AND HELP HIM IMPROVE

COMMUNICATIONS

- ESTABLISH REVIEW REQUIREMENTS
- COMMUNICATE CHANGE STATUS
- ESTABLISH MEETING PLAN
- AWARD FEE CONTRACTS
- FIND THINGS TO COUNT

TYPES OF CONTRACTS

- FIXED PRICE
  - FIRM FIXED PRICE
  - FIXED PRICE WITH ESCALATION
  - FIXED PRICE REDETERMINABLE
  - FIXED PRICE INCENTIVE
  - FIXED PRICE LEVEL OF EFFORT
- COST REIMBURSEMENT
  - COST
  - COST SHARING
  - COST PLUS FIXED FEE
  - COST PLUS AWARD FEE
  - COST PLUS INCENTIVE FEE
- OTHER
  - TIME AND MATERIAL
  - LABOR-HOUR

ADVISORY GROUPS

- ESTABLISH ADVISORY GROUPS
  - TECHNICAL
  - FINANCIAL
  - SCIENTIFIC

COST CREDIBILITY IN A RESOURCE LIMITED COMPETITIVE ENVIRONMENT

JAMES D. CLOUD
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Why is cost credibility so much more important today? One primary reason is the spiraling rise in the cost of defense systems including those costs which are necessary to ensure and assure mission success. After all, part of the cost rise in aircraft, as depicted in Figure 1, has been due to your requirements for assurance that the weapon systems which have an ever increasing cost associated with it, can and will perform its intended function. Obviously such a rise in the cost of systems must be driven by increased requirements for performance, capability, and reliability thus resulting in fewer systems to accomplish the intended functions. This is obviously borne out by Figure 2. There are doubters, however, who claim that it is not the increased performance which is reducing the required number of aircraft but the dollars available to purchase aircraft.

This is an alarming chart and it is statistics such as this that I'm sure led General Slay in his recent speech to the Reliability and Maintainability Symposium to state that "If things keep going the way they are, we may eventually get to the point where we have a modern day Calvin Coolidge suggesting that we only buy one airplane and let everyone take turns." Well, I'll go General Slay one better; I'll say that if things don't improve by the year 2000, we will only be able to afford one airplane per year. Since many of us are engineers, we can extrapolate that data fairly easily.

These rising costs of systems makes the cost credibility of our industry more and more suspect. Despite this negative pall that hangs over us, everyone in this room is striving to improve our performance in mission capability, reliability, maintainability, and with lower cost. What we face today that is unlike anything we have faced since World War II is that we are attempting major programs in the face of severe resource limitations. These resource limitations apply to the government as well as industry.

I would like to briefly describe some of these resource limitations--some which are familiar and some you may not have focused on. All have or will have an impact on the way we do business, our costs and our cost credibility.

Let's take the easy ones first; the government's limited resource in dollars and thus in program opportunities. If we stay close to home, let's look at Space Division's constant dollars and major program starts in Figure 3. When we remember that space is barely 20 years old this is hardly an exploding field of opportunities. One major program start every three years and a near constant dollar budget despite the fact that space communications, surveillance and defense are all relatively new and growing fields of technology, application and exploitation. Cost credibility is vital in the face of this limitation because without proper planning for the dollar resources there will be no system to work our mission assurance on. Part of the answer lies in the judicious application of fixed price or incentive contracts but the fallacy here is the assumption that F.P. or F.P.I. ensures cost credibility. The government often

views (Figure 4) cost credibility on a sharply falling scale with contract type, while industry often sees little difference in its ability to project actual costs. The real driving force in cost is not the contract type but the degree of definition and the stability of firm requirements. So what, say the government contracting officers--fixed price is still fixed price to the government no matter what the contractor's cost. Not so, there are many ways to skin the cat and in industries' view there are some standard approaches to working unexpected cost problems under the type of contract employed, as shown in Figure 5. The records are full of fixed price contracts that had major cost growth from Navy ships to Air Force aircraft.

The wall between the government and the contractor is there to represent the ability of the contractor to obtain changes, waivers or deviations to the contract in order to help solve cost problems. This wall or the inability to waiver or change the fixed price contract poses the greatest threat or risk to the contractor for millions can be spent on insignificant performance parameters. That was one reason the incentive contract was structured, devised to give some flexibility on both sides. The trouble with most incentive contracts is that they revert to either fixed price or cost type under the strain of major cost problems since the share lines are normally negotiated to handle so called "normal problems." The message here is simple, the drive for steeper share lines does not necessarily motivate the contractor under severe cost problems. Finally, we come to the old, much aligned cost plus fixed fee. Let me tell you from years of experience that there is no other contract type where the government and industry work closer together to solve cost problems.

There is another government shortage which is not so obvious but which can have major impacts on our cost credible future--manpower shortages in the officer and civilian support side of the house, Figure 6. Believe me, there is nothing so frustrating or more costly to a program than a government project office that is so understaffed that timely decisions are impossible. This viewgraph gives a quick look forward and backward at the officer level problem in AFSC. Space Division has a compounded problem that all of us in the Los Angeles area face--high property values. For a junior grade officer to be able to afford a house within 25 miles of the Space Division, he would have to be moonlighting with two or three extra jobs. Other than government housing, I know of no solution to their problem.

Let's take a look at the industry side of the ledger in terms of its resources. Manpower, no oversupply since the disastrous slump in the early 70's. In fact, as Figure 7 shows, we hit a 20 year high in 78 and continued that growth in 79. The painful slump after the Vietnam war is evident and we are still suffering today from its effects. Perhaps the best indicator of that shortage is the degree to which we are competing for them as shown by the advertising index, Figure 8. We are scrambling for them with five times the intensity we did 10 years ago, and the actual employment of over 400,000 in R&D exceeds by almost 10% the numbers that were employed in the late 60's. Engineering graduates are expected to average 50,000/year through the 1985 time period with an anticipated demand of over 56,000/year. There appears to be no short term solution other than a major depression and none of us want that to occur.

Oil is not the only scarce commodity in this country since 1974. Let's take a look at one critical material, beryllium, Figure 9. Pure beryllium, is now processed by only one refiner, Brush-Wellman in Pennsylvania. Lead times can run 10 to 14 months and for special titanium, 24 months has been quoted.

Electronic components and especially the high reliability types that we need for our business have always been a problem for our industry. The reason, of course, is obvious, small quantities with extreme quality requirements. Our ability to get the interest of electronic components industry has been declining over the last 20 years and commercial sales are the reason why (Figure 10). The data was only available through 76 on this particular study and the situation today is even worse. The large dollar market now and in the future will lie in commercial sales and more and more component manufacturers will turn their backs on low volume, high reliability parts. This loading of the industry reflects directly in lead times. From a study done within Hughes (Figure 11), lead times for various components have grown over the last seven years by factors of two to four and no parts are unaffected. These lead times are only averages and do not include hybrids which have been running 12 to 14 months lately. Of course, everyone has their own horror story here, and many specific examples of 18 months and even two years can be quoted.

The newest limited resource that has begun to impact us in the last five years is available capital. The scarcity of capital is reflected in the prime commercial bank loan rate, Figure 12. Prior to 1979, no one except controllers paid much attention to prime rates. Now that 20% has been reached and we have all experienced the credit crunch, most of us are familiar with prime rates. Primes have backed off about 1% since the all time high of 20% in March, but most financial people feel that low primes under 10% are gone for some time to come.

So how does that impact our business? Well, for one thing the desire to pursue more fixed price contracts on the government's side will meet with increasing resistance from industry unless some existing policies are modified.

All businesses require investments in facilities, machinery and equipment, and working capital. The defense business has traditionally required less investment in working capital than commercial businesses because the government provides a portion of the working capital investment through progress payments. In recognition of this, defense contracting profit margins on cost or sales are substantially lower than those of commercial businesses. Progress payments at an 80% rate do not provide full financing of the contractor's working capital requirements and, in fact, would not even at a 100% rate. On the average, 80% progress payments finance approximately 60% of the contractor's inventories and receivables and he must finance the balance. This difference is caused by a number of factors, most of which are determined by government procurement policies. First, certain costs such as vendor and subcontract costs are not billable for progress payment purposes until they are paid and, therefore, vendor liabilities are not a net source of contractor financing. Second, progress payments do not recognize unallowable costs. This reduces the 80% rate to an effective rate of less than 78%.

Third, the progress payment system has several built-in lags which result in the receipt of progress payments lagging substantially beyond the time when the contractor must pay his bills.

The current normal 80% progress payment rate was established at a time when the prime interest rate operated in the 6 to 8% range. Even then, it took about 3.8% of negotiated profits to pay for the interest and other unallowable costs and to break even on a typical 12-month fixed-price production contract. Now, with the prime interest rate operating in the 20% range, it takes about 7.5% of negotiated profits to break even on the same contract. In order to keep today's contractor in the same profit position that he was in when interest costs were in the 6 to 8% range, contract profits would have to be increased by about 3.7% or, alternatively, the normal progress payment rate would have to be increased, from 80% to 100% of incurred cost.

This is shown graphically on the next two figures (13 and 14), first realized profit as a function of borrowing rate. You will notice that the extra one-half month lag in progress payments that many of us are realizing now costs us 1% point in fee. It's obvious why the accounts receivable people are a pain in the neck these days.

The second graph, Figure 14, presents the progress payment necessary to hold a constant fee rate at various borrowing rates. You will notice that with a 1.5 month lag, 100% progress payments are required at a 15% borrowing rate and it has been many months since any of us have seen that rate.

Let me give you another example of why so many companies shy away from government fixed price contracts, Figure 15. This is a cash flow comparison of a typical 100 million dollar program of four years duration. A comparison is made of a 10% CPFF versus a 15% fixed price and you will notice that when interest earned is considered only a 1% difference results. We have not been too successful in negotiating 15% fees even on fixed price contracts, so I have also plotted the EDSG experience over the last seven years on fixed price contracts which average out at 4.3%. When the interest paid is considered on this experience curve, you will note than an additional three million is lost from the fee at a 20% borrowing rate or an effective fee rate of 1.3%. Not exactly a smashing business.

So in the face of these problems, how do we maintain cost credibility? Well, we have two major areas to address, proposal up to competitive award, and post award or on-going contracts.

Let's take a look at the pre-award cycle, Figure 16. The normal program starts 24 months before the government fiscal year in which actual dollars would be appropriated and 36 months before any program start. Fiscal guidance is established by the Secretary of Defense at -16 months, the services response in the form of POM at -14 months and so forth. A long and torturous cycle is involved and many interactions between the services, the Secretary of Defense, the budget bureau and the Congress.

What is often the result is a built in funding problem, as shown in Figure 17. Government and industry take too little time in clearly defining the program and cost at the early phase. How many of you have asked or been asked to supply rough order of magnitude numbers by Monday of next week? As a result, insufficient funds are requested and backed into the budget. The long interval between POM budget submission and RFQ allows another phenomenon to take place--additional system definition and inflation. This cycle leads to the ultimate cost growth problem.

The government's answers to these problems have been design-to-cost programs, pre-RFP release, and fixed price and incentive programs. More should be done by both government and industry. First, industry should be requested to participate more often in the cycle and should insist on adequate time for response. Second, more requests should be made for a spread of costs numbers reflecting our estimate of the degree of uncertainty in the program requirements, technology and schedule achievability. In this regard, more use should be made of cost models but improvements or at least sophistication in their use is required. What we need is a good Monte Carlo cost analysis program that can account for the variables of design firmness, likely program funding, inflation and interest rates, component availability and manpower uncertainty. Third, we must both be mature enough to accept the fact that the program may not be important enough to our country to tolerate the reasonable expectancy of cost.

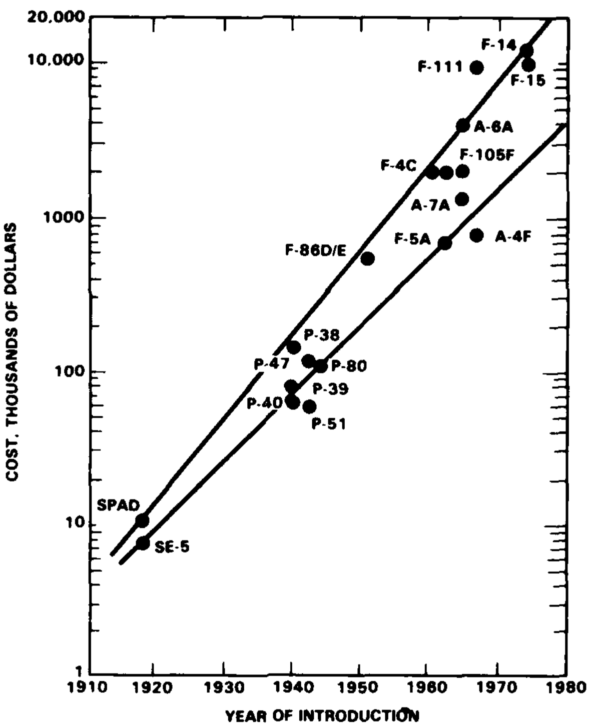
In the post award period, both industry and government have roles and responsibility to maintain cost credibility (Figure 18). Industry certainly must be willing to adopt early problem warning systems such as earned value and to conduct their business where dollars and schedules are as paramount as the performance of their products. Government in turn must define its program needs, establish firm funding profiles or multi-year funding. As a minimum, we should both have the courage to admit that the risk, technical or funding is too great to proceed into high expenditure phase of the program.

In summary, let me say that our resource limitations are real. We do have declining real-dollar Space Defense budgets, fewer new program starts, declining military experience level, industry engineering, material and component shortages. We are experiencing high inflation and interest rates, and the general business environment seems to be increasingly unstable.

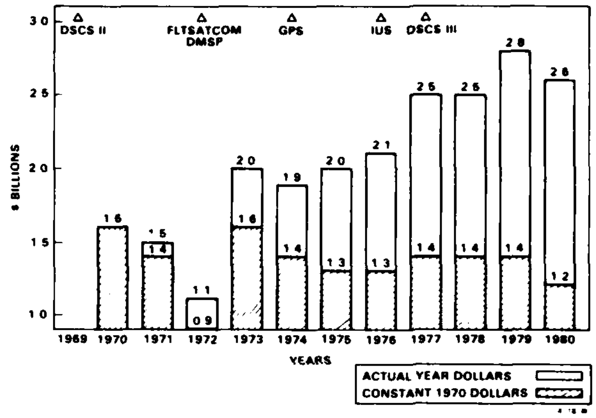
But all is not doom and gloom, particularly with respect to cost credibility. General Slay's new initiatives for multi-year procurements, selection on the basis of past performance, draft RFP's and the desire to get the Air Force procurements on a more commercially oriented basis are all steps in the right direction. I believe that limited resources and full capacity will aid the government in obtaining cost credible proposals since industry will be looking carefully at the risk versus the profit gain. Finally, I believe the government will recognize the rising cost of capital and the growing capital equipment intensity of our industry. This recognition will force the government to improve the incentives offered in order for industry to enter into fixed price contracts.

COST CREDIBILITY IN A RESOURCE-LIMITED COMPETITIVE ENVIRONMENT

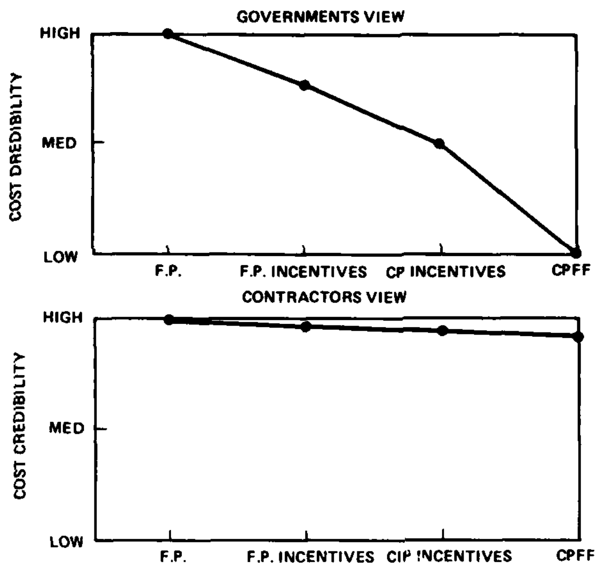
COST OF COMBAT AIRCRAFT



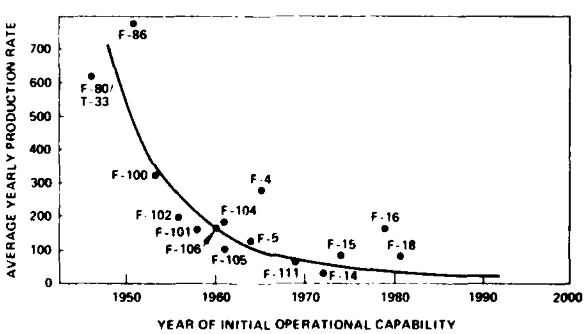
SPACE DIVISION
11 YEAR TOTAL FUNDING HISTORY



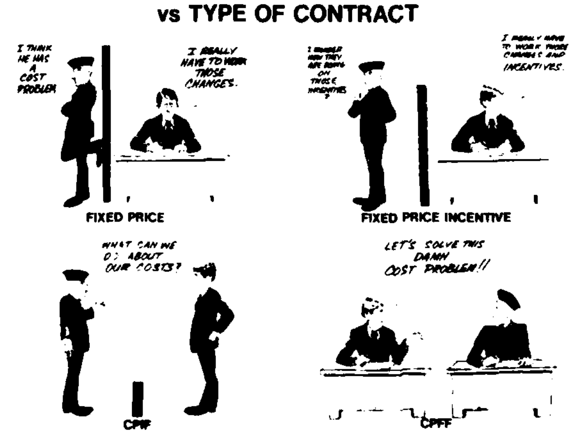
DIFFERENT VIEWS ON COST CREDIBILITY



TREND OF DECREASING YEARLY PRODUCTION RATE OF FIGHTER AIRCRAFT



HOW COST PROBLEMS ARE SOLVED vs TYPE OF CONTRACT



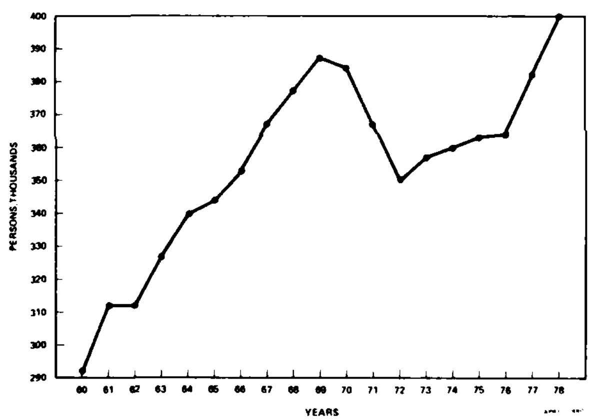
SPACE DIVISION MANPOWER FORECASTS SHOW DECLINING EXPERIENCE LEVEL

- AFSC TOTAL OFFICER PERSONNEL CONSTANT DURING LAST FIVE YEARS — BUT AVERAGE RANK SLOWLY DECLINING
- PROJECTIONS FOR NEXT FIVE YEARS
    - FEWER HIGHER RANKING OFFICERS
    - MORE LOWER RANKING OFFICERS
    - SUPER-SPO's STAFFED FIRST WITH BEST TALENT
    - LOWER PRIORITY PROGRAMS MAY BE INADEQUATELY STAFFED
- NO SHORT-TERM SOLUTIONS
- EDUCATION/EXPERIENCE UPGRADING OF JUNIOR OFFICERS LONG-TERM SOLUTION

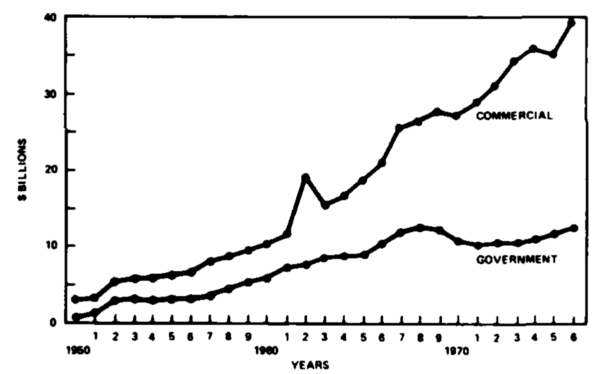
CRITICAL RAW MATERIALS SHORTAGES

- PURE BERYLLIUM NOW PROCESSED BY ONLY ONE REFINER
    - ALL DOMESTIC BERYLLIUM MINED IN DELTA, UTAH
    - BRUSH-WELLMAN IN PENNSYLVANIA ONLY REMAINING REFINER
        - LEAD TIMES SIX TO NINE MONTHS FOR LARGE BILLETS NEEDED FOR LWIR TELESCOPES
        - MACHINING TIME ADDS FOUR TO FIVE MONTHS
    - KAWECKI-BERYLCO INDUSTRIES, INC (KBI) IN PENNSYLVANIA WITHDREW FROM REFINING IN MAY 1979, APPARENTLY DUE TO PROJECTED DEMAND DECLINES (DEMAND NOW SOARING) AND OSHA ISSUES
- SIMILAR PROBLEMS EXIST FOR TITANIUM

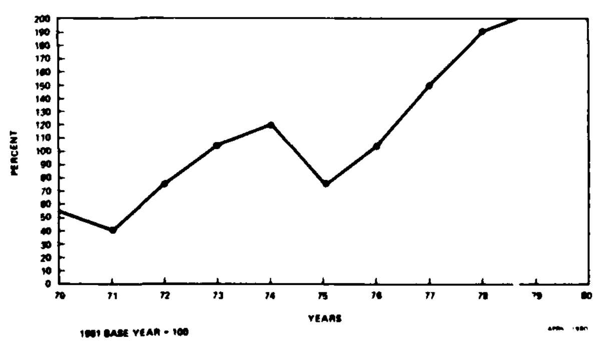
EMPLOYMENT OF SCIENTISTS AND ENGINEERS FOR R&D



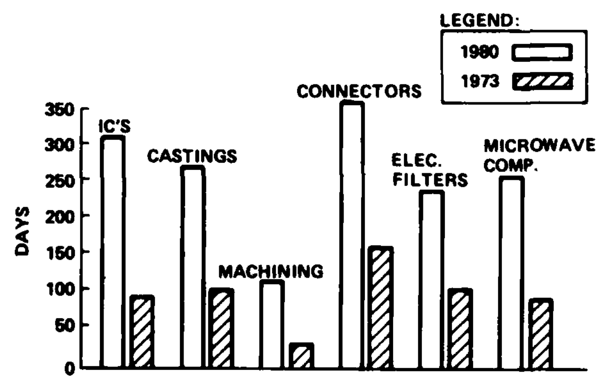
TOTAL ELECTRONICS SALES BY YEARS 1950 - 1976



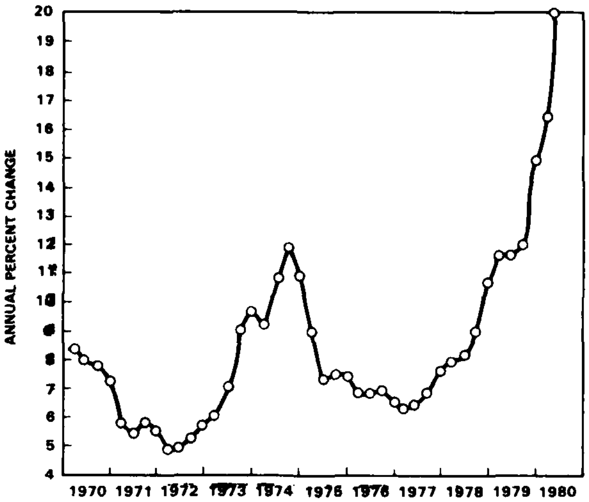
ENGINEER/SCIENTIST EMPLOYMENT ADVERTISING INDEX



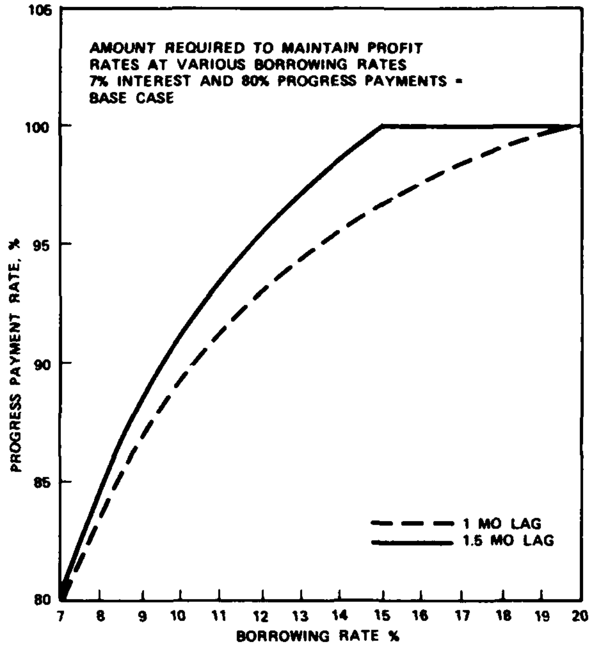
LEAD TIME COMPARATIVE ANALYSIS 1973 vs 1980



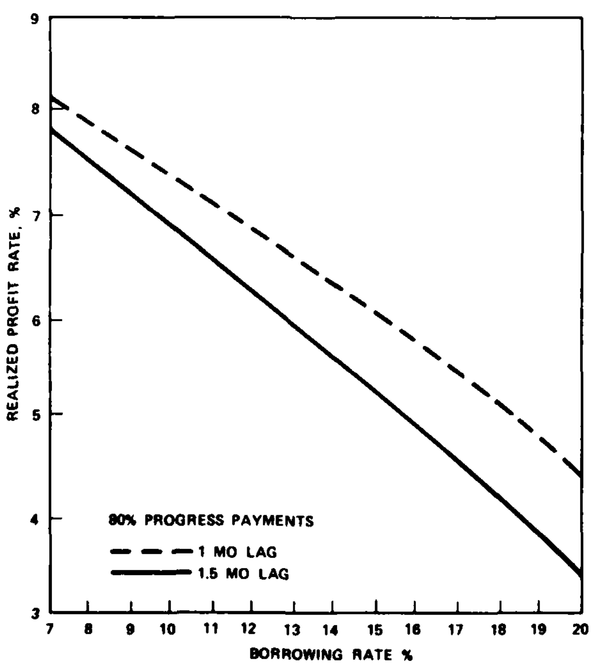
PRIME COMMERCIAL BANK LOAN RATE



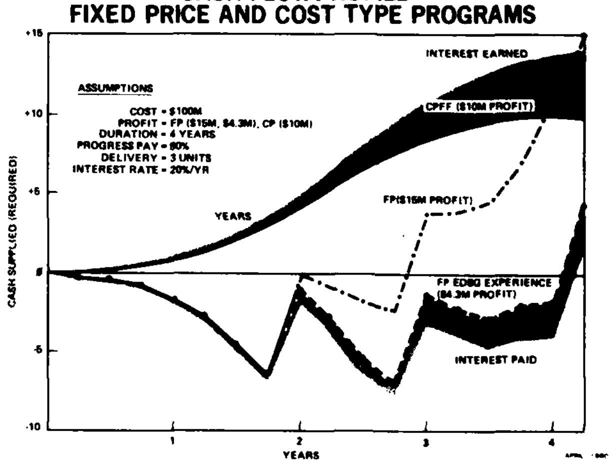
PROGRESS PAYMENT RATES



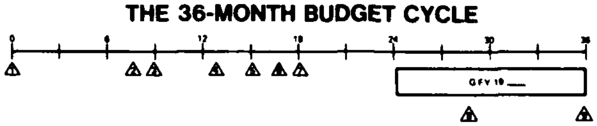
REALIZED PROFIT RATES VERSUS BORROWING RATE



CASH FLOW PROFILE FIXED PRICE AND COST TYPE PROGRAMS

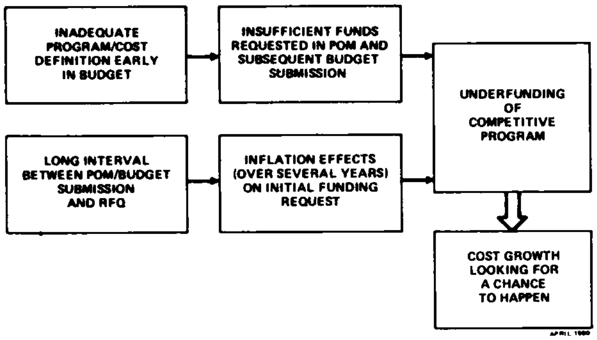


THE 36-MONTH BUDGET CYCLE



BUDGET EVENT		MONTHS FROM FISCAL YEAR START
1 START	JCS/NSC KICK OFF	24 MONTHS
2 FISCAL GUIDANCE (FG)	SEC DEF BOGEYS	16
3 PROGRAM OBJECTIVE MEMO (POM)	SERVICE RESPONSE	14
4 PROGRAM DECISION MEMO (PDM)	SEC DEF DECISIONS	11
5 SUBMISSION	DOD TO OMB	9
6 PROGRAM BUDGET DECISION (PBD)	ADMIN. DECISIONS	7
7 PRESIDENTIAL BUDGET REQUEST (PBR)	PRESIDENT TO CONGRESS	6
8 APPROPRIATIONS BILL	CONGRESS' DECISIONS	+ 5
9 END OF FY CYCLE		+ 12

IMPACT OF 36-MONTH BUDGET CYCLE ON COST CREDIBILITY



ESTABLISHING PROGRAM COST CREDIBILITY AFTER AWARD INDUSTRY AND GOVERNMENT RESPONSIBILITIES

- INDUSTRY
  - EARLY PROBLEM WARNING SYSTEMS
    - EARNED VALUE
  - DEFINE COST AND SCHEDULE RESPONSIBILITY AT A LEVEL WHERE THE DOLLARS ARE SPENT
  - CREATE A WORKING ENVIRONMENT IN WHICH IT IS FELT PROBLEMS CAN BE EXPOSED
  - MUST DEVELOP REPORTING FORMATS THAT
    - IDENTIFY THE KEY PARAMETERS
    - SHOW HISTORY
    - CORRELATE PROBLEMS TO COST AND SCHEDULE DEVIATIONS
  - BASE SALARY REVIEWS OF COST AND SCHEDULE PERFORMANCE NOT JUST TECHNICAL PERFORMANCE
  - DEVELOP DATA BASES ON PAST PROGRAMS TO BE UTILIZED DURING BIDDING
- GOVERNMENT
  - BETTER DEFINITION OF PROGRAMS (i.e. LESS REDIRECTION)
  - RECOGNIZE THE DIFFERENCES IN COST VARIABILITY OF DEVELOPMENT VERSUS PRODUCTION PROGRAMS
  - MINIMIZE THE FISCAL YEAR FUNDING CONSTRAINTS
  - COST VERSUS BENEFIT TRADEOFFS OF GOVERNMENT CONTRACTOR SUPERVISION VERSUS LAISSEZ-FAIRE

MANAGEMENT OF PROGRAMS

Don Hurta
Naval War College

The Concepts and Tools of Risk Management

The objective of this workshop is to discuss the application of risk methodology to the function of Program Management. A short presentation will be made on the concepts associated with risk analysis, risk assessment and risk management. The workshop will then discuss the potential application of these concepts as a program management tool during the program acquisition and the program implementation phases. Recommendations will be made as to where risk analysis and assessment should be applied and how risk mangement can be used to support effective program implementation and communication. Particular emphasis will be placed on the potential characterization of the risk as an inherent element of schedule, cost and performance management.

A set of analytical tools is applied to quantify risk as a function of variables of probability of success and and consequence of failure. It is maintained that the characterization of a system model, coupled with the use of risk analysis tools will provide management insight into technical, cost and schedule trade offs, ECP management, cost sensitivity analysis and decision-making.

Basic concepts and tools of risk analysis will be presented to the splinter workshop group, including the risk function, risk modeling techniques, and the development of system models. Discussions will be held to evaluate the follwoing questions:

1) Given program funding and schedule constraints, can this technique be used to assist the program manager in meeting performance objectives?

2) Where can the risk management techniques be best used to enhance the attainment of mission assurance goals?

3) Can this technique be used to emphasize the need to be responsible to program goals, rather than dictate program requirements (eg, A109)?

4) How effective are these techniques in supporting trade-offs analyses and preventing "goldplating"?

5) Do the techniques of risk management provide objectivity to the establishment of minimum acceptable standards for mission assurance?

6) Do risk management techniques apply to both government and industry? .....to prime contractors and subcontractors? If so...how?

7) Who is responsible in the program organization for risk management?

8) How effective is risk management as a communications vehicle?

9) Can risk management techniques be used to establish contract incentives?

10) Is there a danger in using these tools too extensively?

11) What are the dangers in treating the elements of the system model independently?

12) Where does judgment and decision-making enter into the process and analysis end?

"WHEN *I* USE A WORD," HUMPTY DUMPTY SAID, IN RATHER A SCORNFUL TONE, "IT MEANS JUST WHAT I CHOOSE IT TO MEAN — NEITHER MORE NOR LESS."

"THE QUESTION IS," SAID ALICE, "WHETHER YOU *CAN* MAKE WORDS MEAN SO MANY DIFFERENT THINGS."

"THE QUESTION IS," SAID HUMPTY DUMPTY, "WHICH IS TO BE MASTER — THAT'S ALL."

THROUGH THE LOOKING-GLASS

LEWIS CARROLL

RISK

PROBABILITY OF FAILURE — CONSEQUENCE OF FAILURE

AGAINST WHAT STANDARD ?
WHAT IS THE GOAL ?
WHAT IS MINIMALLY ACCEPTABLE ?

DOUGLAS MacARTHUR'S CREDO

EVERY MISTAKE IN WAR IS EXCUSABLE EXCEPT INACTIVITY AND A REFUSAL TO TAKE RISKS.

...SAID BY H.H. FROST

...QUOTED IN <u>AMERICAN CEASAR</u>

NO RISK IS THE HIGHEST RISK OF ALL

AARON WILDAVSKY

RISK MODELS

RISK PROFILES

UTILITY

MULTI-ATTRIBUTE UTILITY

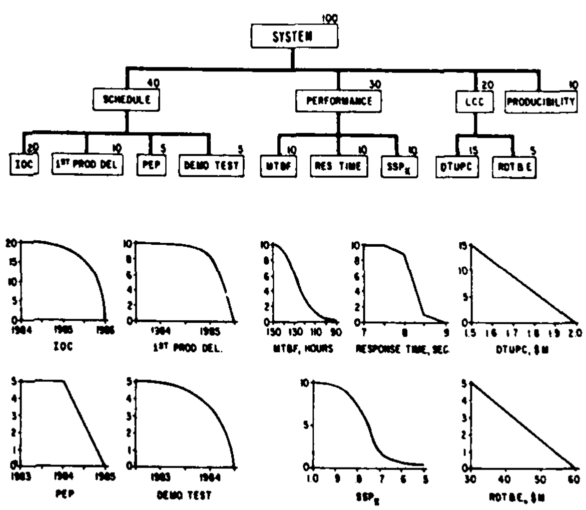
ISO-RISK CONTOURS

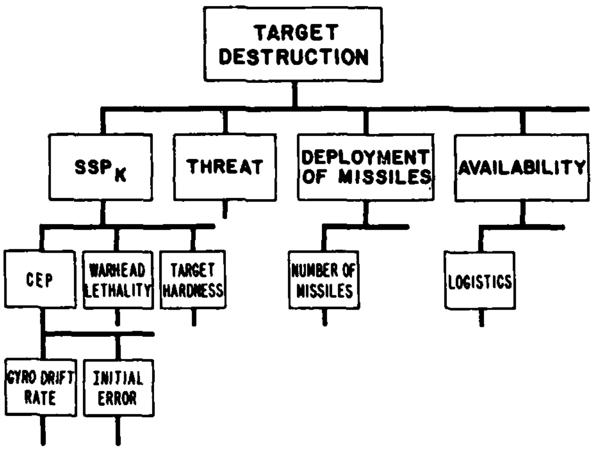
NETWORKS

(MODIFIED) DELPHI

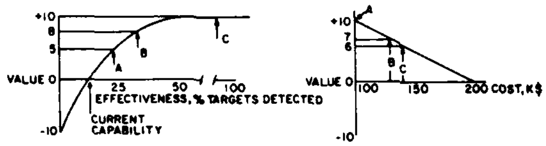
IN ORDER TO WIN YOU MUST RISK LOSS

JEAN-CLAUDE KILLY

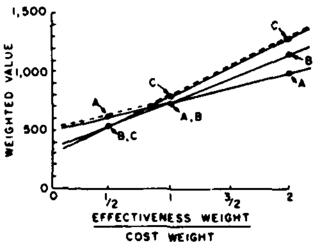


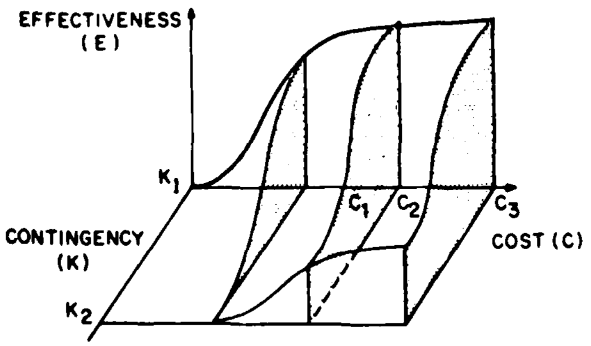


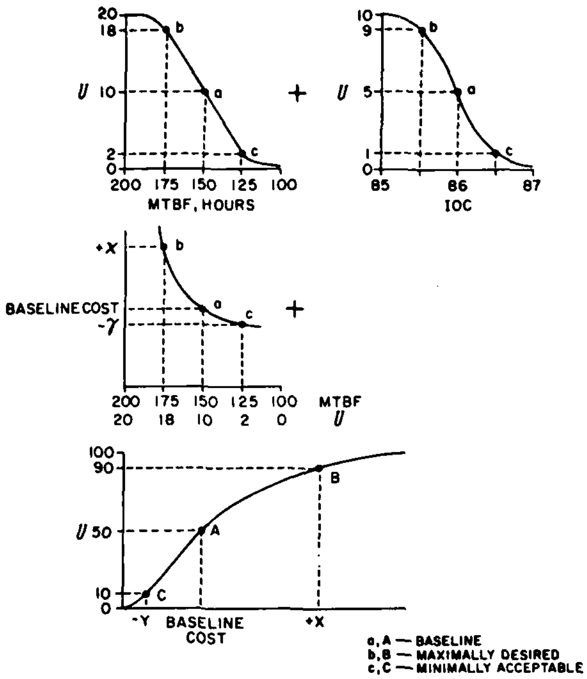
SENSITIVITY ANALYSIS, WEIGHTS



		VALUE		
	WEIGHTS	A	B	C
EFFECTIVENESS	50	+5	+8	+10
COST	50	+10	+7	+6
WEIGHTED VALUE		750	750	800
DOUBLE EFFECTIVENESS WEIGHT				
EFFECTIVENESS	100	5	8	10
COST	50	10	7	6
WEIGHTED VALUE		1000	1150	1300
EFFECTIVENESS WEIGHT				
EFFECTIVENESS	25	5	8	10
COST	50	10	7	6
WEIGHTED VALUE		625	580	580







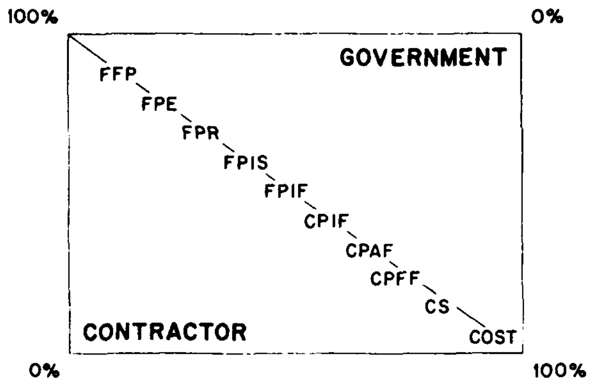
"...... MEASURING COST-EFFECTIVENESS (IS) OF LIMITED USE IN STRATEGIC PLANNING BECAUSE THE RANGE OF OPTIONS IS ACTUALLY RESTRICTED BY POLITICS. MOREOVER........ THE SEEMING PRECISION OF COST-EFFECTIVENESS (GETS) IN THE WAY OF REAL UNDERSTANDING OF THE MOST DIFFICULT PROBLEMS IN DEFENSE WHICH INVOLVE VALUE JUDGEMENTS......"

JAMES SCHLESINGER
1963

SUMMARY OF MULTI-ATTRIBUTE UTILITY LEARNING OBJECTIVES

- ATTRIBUTES
  - INDEPENDENT
  - EXHAUSTIVE
- WEIGHTS
  - RELATIVE
  - ADDITIVE
- UTILITY FUNCTIONS
  - SHAPES LIMITED ONLY BY INGENUITY
  - REFLECT WEIGHTS
  - BASELINE
  - MINIMALLY ACCEPTABLE
  - MAXIMALLY DESIRED
- ALTERNATIVE CHOICE CONSIDERATIONS
  - PROPER INPUTS
    - DECISION MAKER - THE MORE PARTICIPATION THE BETTER
    - EXPERTS - WITH RATIONALE
  - DISCRIMINATION CAPABILITY
  - MODEL LIMITED
    - NON-QUANTIFIED FACTORS
    - REQUIREMENTS
  - SENSITIVITY ANALYSES
- DO ONE....

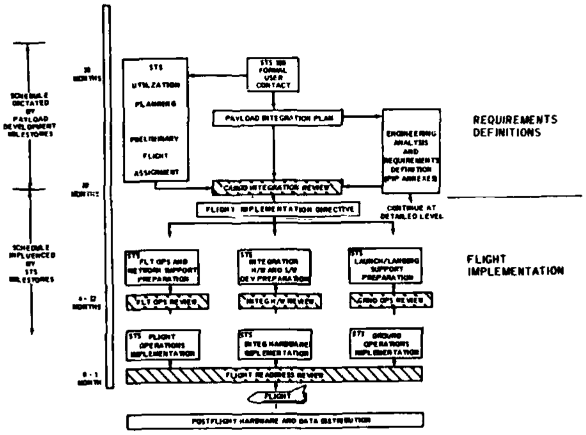
RISK



STS PAYLOAD INTEGRATION

Leonard Nicholson
Johnson Space Center

STS/PAYLOAD INTEGRATION PROCESS



STS/PAYLOAD DOCUMENTATION

DOCUMENT	PURPOSE
• PAYLOAD INTEGRATION PLAN	• DEFINE ROLES AND RESPONSIBILITIES • DEFINE TASKS/WORK TO BE DONE • ESTABLISH BASELINES, GUIDELINES AND CONSTRAINTS FOR INTEGRATION AND PLANNING • ESTABLISH SCHEDULE FOR ALL INTEGRATION ACTIVITIES
• PAYLOAD INTEGRATION PLAN ANNEXES	• DOCUMENT AGREED UPON PAYLOAD IMPLEMENTING PROCEDURES, TIMELINES, PROFILES, AND PLANS WHICH STS WILL BE REQUIRED TO EXECUTE • DOCUMENTATION OF DETAIL DATA LISTS AND REQUIREMENTS NECESSARY FOR STS TO BUILD FLIGHT/GROUND SOFTWARE OR TO CONFIGURATE FLT/GND SYSTEMS FOR IMPLEMENTATION OF PAYLOAD MISSION
• PAYLOAD/STS ICD	• DEFINE DESIGN AND SPECIFICATIONS FOR INTERFACES BASELINED IN THE PIP • ESTABLISH ENVIRONMENTS FOR DESIGN PURPOSES
• SAFETY DOCUMENTATION • HAZARD REPORT FORMS • COMPLIANCE REPORT • HAZARDS PROCEDURES	• ESTABLISH HAZARDS TO BE CONTROLLED • REACH AGREEMENT OF METHODS FOR HAZARD CONTROL • ESTABLISH METHODS FOR VERIFYING COMPLIANCE WITH SAFETY REQUIREMENTS

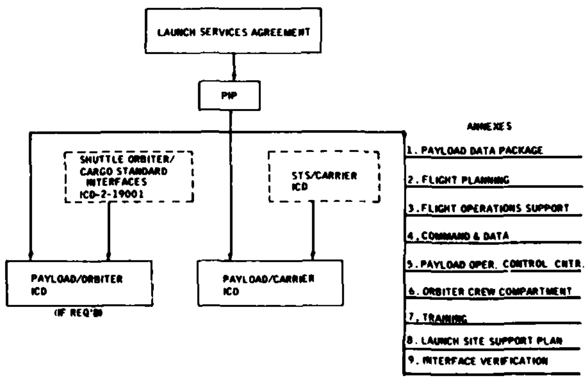
PAYLOAD INTEGRATION PLAN

- PURPOSE
  - DEFINE PAYLOAD/STS ROLES AND RESPONSIBILITIES
  - DEFINE TECHNICAL BASELINE FOR IMPLEMENTATION
  - ESTABLISH GUIDELINES AND CONSTRAINTS FOR INTEGRATION AND PLANNING
  - DEFINE TASKS TO BE ACCOMPLISHED
  - ESTABLISH SCHEDULE FOR ALL INTEGRATION ACTIVITIES
  - ESTABLISH BASIS FOR DEFINITION AND PRICING OF OPTIONAL SERVICES
- ORGANIZATION AND SCOPE
  - ORGANIZED BY MAJOR DISCIPLINES i.e., LEVEL I GROUNDRULES/RESPONSIBILITIES, ENGINEERING, FLIGHT OPERATIONS, AND GROUND OPERATIONS
  - INCLUDES ALL STS INTERFACES WITH THE USER

PAYLOAD INTEGRATION PLAN ANNEXES

- FLIGHT PLANNING
  - CREW ACTIVITIES PLAN/EVENT SEQUENCE
  - POWER, ATTITUDE, THERMAL PROFILE
  - TRAJECTORIES/LAUNCH WINDOWS
- PAYLOAD DATA PACKAGE
  - SEQUENCED MASS PROPERTIES
  - CONFIGURATION DRAWINGS
  - RF RADIATION DATA
- POCC REQUIREMENTS
  - VOL I - JSC POCC REQUIREMENTS
  - VOL II - MCC TO REMOTE CENTER INTERFACES
- COMMAND AND DATA
- CREW COMPARTMENT STOWAGE/INSTALLATION
- LAUNCH SITE SUPPORT PLAN
  - PROCESS PLAN
  - FACILITIES AND SERVICES
  - CHECKOUT PROCEDURES
- TRAINING
  - FLIGHT CREW
  - GROUND CREW
- FLIGHT OPERATIONS SUPPORT
  - OPERATIONS PLAN
  - MISSION RULES
  - DATA EXCHANGE TIMELINES
  - PROCEDURES
- INTERFACE VERIFICATION
  - INTERFACE VERIFICATION MATRIX OF ICD
  - UNIQUE VERIFICATION REQUIREMENTS

STS/PAYLOAD REQUIREMENTS DEFINITION DOCUMENTATION



CARGO COMPATIBILITY

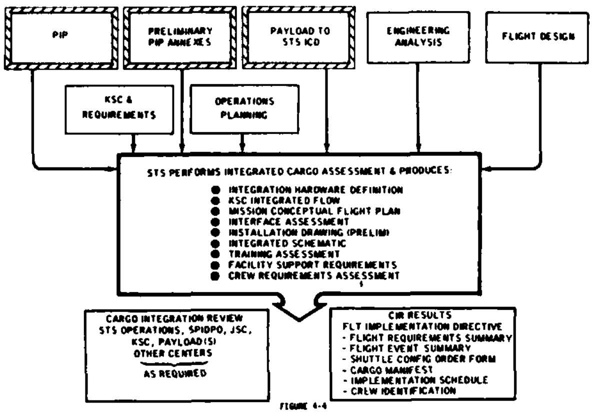


FIGURE 4-4

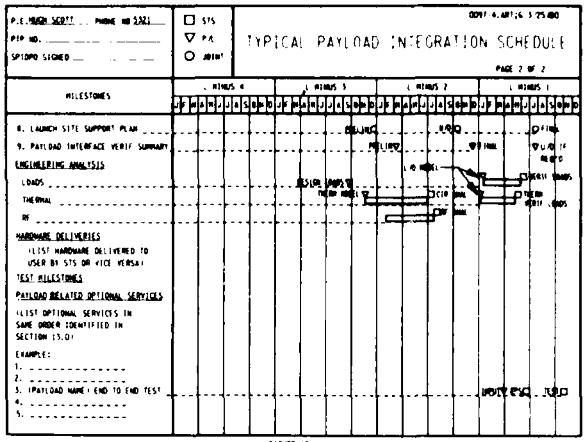


FIGURE 15 1

STS FLIGHT IMPLEMENTATION PHASE

CARGO INTEGRATION RESULTS

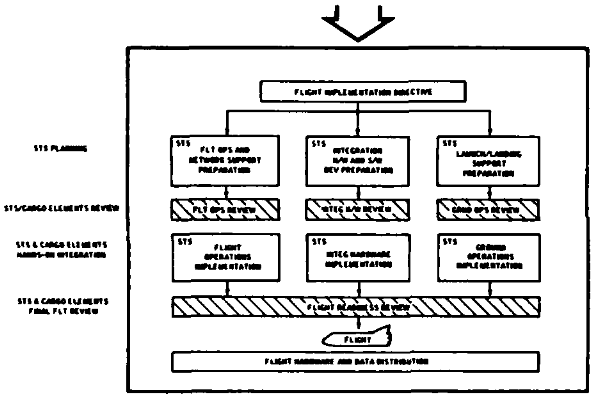


FIGURE 5-1

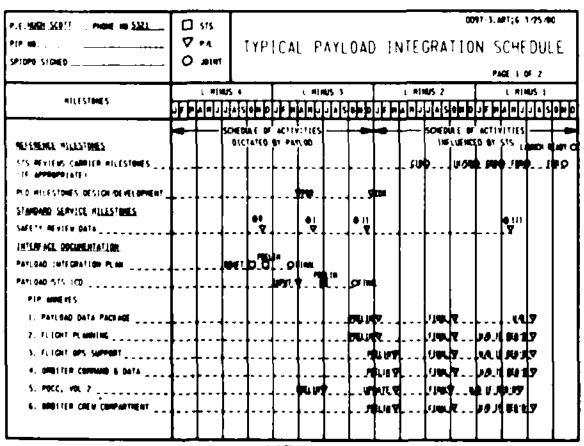


FIGURE 15 1

FUTURE CHALLENGES FOR
REUSABLE SPACE SYSTEMS

28 April 1980

Ben Wier
General Dynamics

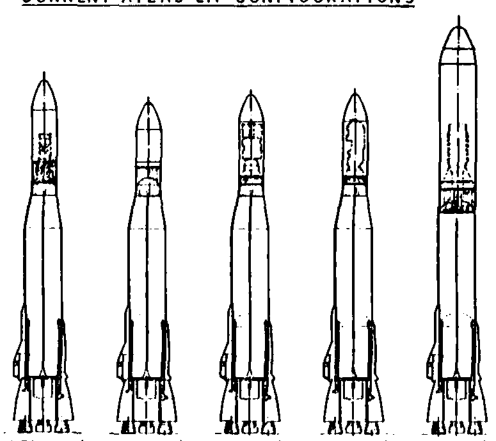
ATLAS E/F LAUNCH VEHICLE PROGRAM

- BACKGROUND
- STORAGE
- REFURBISHMENT AND MODIFICATION
- PROGRAM TIME ADJUSTMENTS
- BRIEF LOOK AT THE 80'S AND 90'S

BACKGROUND

- OPERATIONAL WEAPON SYSTEM IN EARLY 60's
- DECOMMISSIONED IN 1965
- STORAGE AT NORTON AIR FORCE BASE, SAN BERNARDINO
- FIRST FLIGHT - 1967
- FLOWN TO DATE
- 25 REMAIN TO BE FLOWN
  - ▲ GLOBAL POSITIONING SYSTEM - PHASE I
  - ▲ GLOBAL POSITIONING SYSTEM - PHASE II
  - ▲ ABSAD PROGRAM
  - ▲ TIROS/NOAA PROGRAM
  - ▲ DEFENSE METEOROLOGICAL SATELLITE PROGRAM
- THIRTY-FOUR OUT OF 35 SUCCESSFUL

CURRENT ATLAS E/F CONFIGURATIONS



VEHICLE	ATLAS E/F SGS	ATLAS E/F AKM	ATLAS E/F OIS	ATLAS E/F BLOCK 5D	ATLAS E/F AGENA
MISSION	NTS, GPS	ABSAD	P78-1	TIROS-N, NOAA	SEASAT

ATLAS E/F MODIFICATION PROGRAM

ATLAS E/F PROCESSING

NORTON AFB (SAN BERNARDINO)

- STORAGE
- PERIODIC INSPECTION
- CORROSION CONTROL
- SHIPMENT TO GDC SAN DIEGO

ATLAS E/F PROCESSING

GENERAL DYNAMICS (SAN DIEGO)

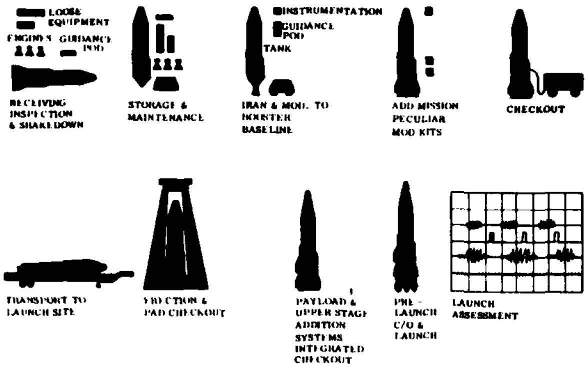
- WELD 84-INCH TANK RING KIT
- FAB BASELINE AND MISSION PECULIAR DETAILS/PARTS
- FAB NEW AUTOPILOTS
- FAB FAIRINGS AND ADAPTERS

ATLAS E/F PROCESSING

GENERAL DYNAMICS (VAFB)

- VAMP
- FAB BASELINE AND MISSION PECULIAR DETAILS/PARTS
- INSTALL MISSION PECULIAR KITS
- LAUNCH SITE MAINTENANCE AND OPERATION
- LAUNCH PROCESSING

VANDENBERG ATLAS MODIFICATION PROGRAM (VAMP)



VANDENBERG ATLAS MODIFICATION PROGRAM (VAMP)

- ALL TASKS ACCOMPLISHED IN BOOSTER ASSEMBLY BUILDING NO. 6 (BAB-6)
- BOOSTER RECEIPT AND INSPECTION
  - ▲ INVENTORY BOOSTER AND LOOSE EQUIPMENT
  - ▲ ACCOMPLISH SHAKEDOWN TO GDC-BRW67-001. DOCUMENT ALL AREAS OF BOOSTER INCLUDING INTERNAL FUEL & LO_2 TANKS PLUS ALL LOOSE EQUIPMENT.
  - ▲ REVIEW ALL BOOSTER HISTORY DOCUMENTATION.
  - ▲ DISCREPANCIES DOCUMENTED ON QUALITY ASSURANCE FORMS 7000 (QAR) AND CATEGORIZED FOR BHRB ACTION.
- BOOSTER HARDWARE REVIEW BOARD (BHRB)
  - ▲ AFSD/LV CHAIRMAN, CONVAIR, SAMTO (6595TH TEST WING AND AFQC), ASSOCIATE CONTRACTORS
  - ▲ APPROVE DISPOSITION OF DISCREPANCIES
- BOOSTER MODIFICATION/REPAIR
  - ▲ ACCOMPLISH BASELINE MODS IN ACCORDANCE WITH CI SPEC. 27-00350 AND ALL OUTSTANDING SPECIFICATION CHANGE NOTICES (SCNs).
  - ▲ ACCOMPLISH IRAN TASKS IN ACCORDANCE WITH QAR DISPOSITIONS.
- COMPONENT RECYCLE/REVERIFICATION
  - ▲ ACCOMPLISH CRITICAL COMPONENT REVERIFICATION IN ACCORDANCE WITH ATLAS E/F PARAMETERS DOCUMENT AND MISSION ASSURANCE PLAN (MAP)
  - ▲ RECYCLE ENGINES IN ACCORDANCE WITH ROCKETDYNE DOCUMENTATION
  - ▲ ACCOMPLISH RUBBER GOODS INSPECTION IN ACCORDANCE WITH ATLAS E/F PARAMETER DOCUMENT
- PERFORM MISSION PECULIAR MODIFICATIONS
  - ▲ ACCOMPLISH CONCURRENT WITH BOOSTER MOD/IRAN WHERE REQUIREMENTS CAN BE DEFINED IN A TIMELY MANNER OR AFTER BASELINE MOD/IRAN
- BOOSTER CHECKOUT AND ACCEPTANCE
  - ▲ CHECKOUT IN ACCORDANCE WITH CI SPEC 27-00350
  - ▲ HARDWARE AND DOCUMENTATION REVIEW BY AFSD/LV, AEROSPACE, AND SAMTO
  - ▲ DD-250 ACCOMPLISHED

TIME AND HARDWARE

- ATLAS MA-3 ENGINE SYSTEM
  - ▲ BUILT IN EARLY 60'S
  - ▲ LAST HOT FIRED IN EARLY 60'S
- CONFIGURATION VERIFICATION
- SOME DISASSEMBLY - BOROSCOPE CHECKS
- EXTENSIVE CONTAMINATION CHECKS
- REVIEW OF PAST ACCEPTANCE DATA
- NO SIGNIFICANT REJECTS AFTER 20 YEARS
- SAME FINDINGS APPLY TO
  - ▲ PROPELLANT TANKS
  - ▲ THRUST STRUCTURE

TIME AND SPECIFICATIONS

- LONG TERM PROGRAMS (10 YEARS PLUS) ADJUST TO CHANGING REQUIREMENTS, E. G.,
  - ▲ ENVIRONMENTAL REQUIREMENTS
    - VIBRATION - SINE/RANDOM/ALL RANDOM
    - TEMPERATURE CYCLING
    - ACOUSTIC REQUIREMENTS
  - ▲ ELECTRONIC PIECE PARTS UPDATE
- AFFECTS PREVIOUSLY QUALIFIED HARDWARE
  - ▲ QUALIFY BY ANALYSIS
  - ▲ REQUALIFY

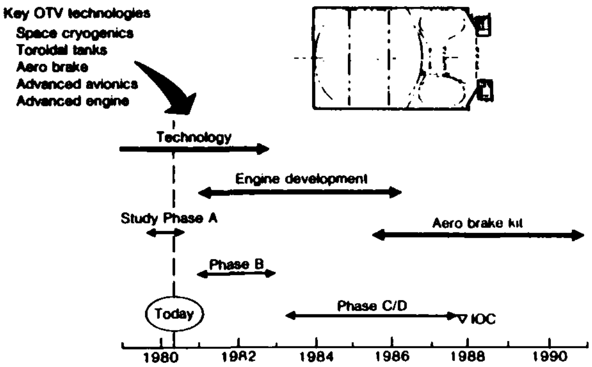
TIME AND LOGISTICS

- HARDWARE VENDOR CHANGES OCCUR DURING SPAN OF THE PROGRAM
  - ▲ BUSINESS BASE CHANGES
  - ▲ OUT OF BUSINESS
- SELECT NEW SOURCE
  - ▲ HARDWARE REQUALIFICATION

SHUTTLE PROGRAM ADDITIONS IN THE 80'S AND EARLY 90'S

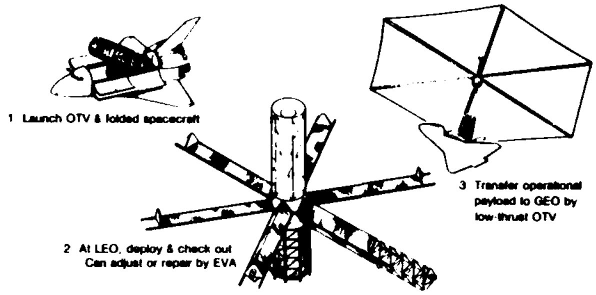
- ORBITAL TRANSFER VEHICLE
- PLATFORMS IN SPACE

OTV DEVELOPMENT PLAN



LOW ACCELERATION OF LARGE SPACE SYSTEMS IS BENEFICIAL

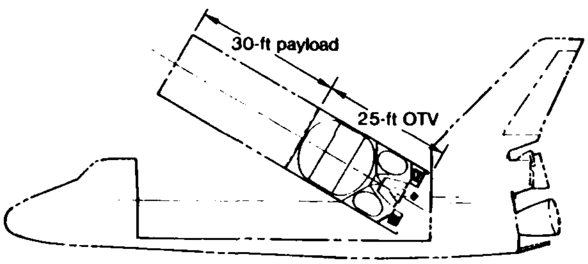
APPLICABLE TO GEOPLATFORM & SPACE RADAR



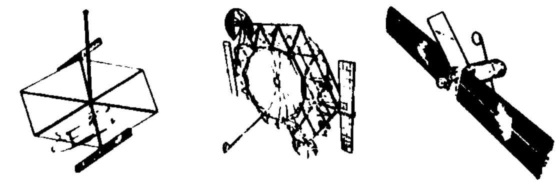
- Large space structure size optimized at low acceleration = 0 05 to 0 3g maximum
- Optimum thrust = 1,000 to 3,000 lb with 15,000 lb spacecraft
  Up to 9 burns during 1-day transfer to GEO
- Low thrust can be achieved by running 15K engine at idle or using new small engine

A LEADING OTV CANDIDATE CONCEPT

- 55,000 lb maximum propellant capacity
- Toroidal tank to reduce length
- Modified RL10 engine with idle mode
- Advanced avionics with return-trip capability
- Cryogenic interfaces with Orbiter & KSC per STS Centaur study
- Deployable aero brake kit for return to Orbiter



LARGE SPACE SYSTEMS ARE A NEW CLASS OF SPACECRAFT



Space based radar	Geo platform	Power array
• Hexagon - circular	• Retangular - hexagon	• Long rectangle
• Central mast + spokes	• Many mass concentrations	• Even mass distribution
• Flexible	• Relatively stiff	• Very flexible
• Low natural frequency	• High natural frequency	• Very low natural frequency

Low acceleration including thrust transients may be vital to large space systems

AVIONICS REQUIREMENTS FOR OTV

10-day round-trip missions
- Guidance update & navigation (space sextant & star tracker)
- Light fuel cells using main propellants

Survivability
- Proteciton from solar flux, Van Allen belt
- Defense against ECM or lasers

Improved redundancy architecture
- Fault-tolerant computers with internal cross-strapping, memory bank sharing, & improved software techniques

Distributed computer arrangements
- Fiber-optics bus
- Very high speed (>450,000 operations per second)

Improved reliability/manrating
- Fault-tolerance/backups
- Condition-monitored maintenance

Advanced avionics provide improved capability for OTV without obsolescence by 1990.

SUMMARY OF ISSUES AND RECOMMENDATIONS

MANAGEMENT OF PROGRAMS

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Government Roles and Responsibilities

Issue

Change Control - To what level should the Government be involved in change control procedures of prime and sub-tier contractors ?

Recommendations

- MIL-STD-483 should be more explicit in the ECP preparation in the area of Mission Assurance. (Contractors should be required to state the total effect on the system of the change involved.)
- Consideration should be given to tailoring the existing standards to suit the particular contract.

2. Cost Estimating

Issue

Cost Estimating and Management - How can the Government get a good cost estimate in the early phases of a program and a continued estimate throughout the program when changes are contemplated ?

Recommendations

- Expand existing cost modeling methods and develop improved methods for independent development of cost estimating.
- Early involvement of contractors in the Government planning process and cost modeling.

3. Flow Down Requirements

Issue

Contracts and sub-tier flow down - Should the Government require flow down and if so to what level ?

Recommendations

- It is the Governments responsibility to require flow down on a case by case basis depending upon the criticality of the contract item. (Items of particular concern are FMEA, failure analysis, change control, etc.)

4. Program Office Personnel Continuity

Issue

Government involvement in details - Some Government offices have inadequate personnel to get involved in sufficient detail in program activities. Early experienced involvement is particularly important.

Recommendations

- Consideration should be given to provide a sufficient number of civil servants positions to provide continuity and early involvement in detailed program planning.

5. Contractor Assistance

Issue

Providing help to the contractor - Does the Government have a responsibility to provide help to a contractor and what are the contractural problems that may be encountered?

Recommendations

- The Government has a responsibility to provide competent help to a contractor in needed areas. Provisions for this

assistance should be included in contract formulation.

6. Up Front Funding

Issue

A contractor study has shown that some contracts have been let with insufficient attention and resource allocation to preventative analyses such as FMEA, single point failure sneak circuit analysis, etc.

Recommendations

- Government should place contractural emphasis and enforce requirements for preventative analysis by contractors and provide sufficient funding and schedule to do an adequate job. The Government must provide adequate resources to review the contractors analysis.
- Consideration should be given to include these analysis as a part of the incentive program for Mission Assurance.
- Industry must provide earlier-more realistic cost estimates.

7. Tailoring of Specifications

Issue

In some agencies inadequate attention has been given to tailoring existing specifications to suit the specific requirements of a program.

Recommendations

- Consideration should be given to providing training programs to increase awareness of Mission Assurance requirements so that existing specifications can be properly tailored at the outset of a program.

8. Communication

Issue

There appears to be a growing adversary situation between the contractor and customer, i.e., both Government and sub-contractor, at both the management and the working level. It could be a result of less informal team interrelationships; perhaps caused by over emphasis of arms length relationship. Information flow seems to be impeded.

Recommendations

- Education of Governnment technical project officers to encourage personal contacts with contractor counterparts while at the same time maintaining ethical standards.
- Motivation to instill a team, goal oriented, spirit for both industry and Government.
- Policy statement to recognize common Government industry goals.

9. Industry Responsibility

Issue

Higher profits in a fixed price environment with higher risks to the contractor is a declared A. F. policy. Is industry willing to accept the challenge in the face of the uncertain economy and uncertain cost of money ?

Recommendations

- Yes, but provisions to protect catastrophic events must be afforded to the contractor. Contractors are willing to accept the risks that fall within their ability to control through good management techniques. A recommendation that might be considered is a form of imputed coverage for working capital

along the lines of cost of money coverage for facilities investments, and to further technology.

- Industry should educate their Government counterparts.

10. Industry Responsibility

<u>Issue</u>

Review of draft RFP's.

<u>Recommendations</u>

- Absolutely essential industry responsibility is a vigorous cooperative constructive review of draft RFP's. The Air Force is more and more providing opportunity - industry must take advantage.

11. Industry Responsibility

<u>Issue</u>

Contract forms - preception exists that the Space Division is baselining on fixed price and NASA on CPAF.

<u>Recommendations</u>

- Although we have experienced variations on the old theme - FP - incentive, award, etc., we must become more innovative and creative. The Air Force is soliciting suggestions and industry should be responsive.

- Earlier planning to identify the appropriate contract vehicle.

12. Payload Integration Management

<u>Issue</u>

Too many organizations in the integration loop for AF missions on shuttle. In the commercial world - JSC interfaces directly with S/C program manager.

<u>Recommendations</u>

- SD review integration management with an eye to shortening the technical and management communication loops.

- Identify deployment modes and environmental constraints.

- Identify design criteria and assure understanding before spacecraft design begins.

13. Payload Integration Management

<u>Issue</u>

There is perception in the shuttle program - that each user has the idea that the shuttle and the shuttle flight is dedicated to his spacecraft.

<u>Recommendations</u>

- The Mission Assurance forum helps disseminate this information and clarify the mixed manifest.

- SPO's should insure that spacecraft contractors comply with mixed manifest concept and constraints - possible communication suggestions:
  - Contract boiler plate
  - Specification
  - Commander's policies

14. Risk Management

<u>Issue</u>

Standardize the methodology and criteria to be used for Risk Management.

<u>Recommendations</u>

- Develope a handbook of Risk Management methodologies and criteria to be used for procurement. The handbook should include several Risk Management approaches so that the program/procurement office can select a

specific approach for a given procurement.

- Validate the multi-attribute utility technique.
- Brief SD procurement personnel.
- Establish a policy on RFP utilization.

WORKSHOP B

DESIGNING FOR MISSION ASSURANCE

Designing for the Shuttle Era. Introduction and Overview by the Sub-Group Chairmen	J.B. Sterett, Marshall Space Flight Center, NASA
Definition, Control and Utilization of Design Requirements	L.G. Williams, Johnson Space Center NASA; Robert Wagner, Aerospace H.E. Emigh, Rockwell J. Eckle, Boeing Marne Mercer, Lockheed, LMSC Paul Christensen, Martin Co.

EFFECTIVE FAILURE ANALYSIS IN THE DEVELOPMENT CYCLE

Introduction and Overview of Session Activities by the Sub-Group Chairman	Paul Dick, General Electric Space Division
A West Coast Aerospace Company's View	Ronald Hanni, Ford Aerospace and Communications Corporation
An East Coast Aerospace Company's View	Rick Simon, General Electric Space Division
The View of a Customer Support Agency	Edgar Doyle, Rome Air Development Center
The View of a Technical Support Agency	Joe Howell, Aerospace Corporation
Break	
CONFIGURATION ITEM SPECIFICATIONS	L.A. Hartman, Lockheed, LMSC Ernie Wade, The Aerospace Corp.

Overview of Workshop Sessions

- SUMMARIZE POSITIONS
- DISCUSS ALTERNATIVES
- REVIEW OF RECOMMENDATIONS

WORKSHOP B

DESIGNING FOR MISSION ASSURANCE

Chairmen

Bernard G. Morias
Program Manager,
Satellite Systems Division
LMSC

Albert T. Finney
Program Manager
Defense SATCOM III,
The Aerospace Corporation

Robert W. Hager, Vice President
Inertail Upperstage
/Spacecraft Integration
Boeing Aerospace Co.

J.B. Sterett
Assistant Director
Test Laboratory,
Marshall Space Flight Center, NASA

Coordinators

Edward H. Newman
Chief, Acquisition
Management Division,

M.A. McGowan
Member of the Technical
Staff, The Aerospace Corporation

WORKSHOP PRESENTATIONS

The Hughes AC Review Process	Don Thibodo, Hughes
Launch Vehicle Design Review Problems	Ed Webster, McDonnell Douglas
Mission Success Through Design Review	Gene Barnett, TRW
Break	
Manned Maneuvering Unit Simulator Design Review Process	Leroy DuCharme, Martin Co.
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EFFECTIVE TECHNIQUES FOR MINIMIZING DESIGN DEFICIENCIES AND IMPROVING ENGINEERING PRODUCTIVITY

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Abstract

In 1976 Hughes Aircraft Company's Space and Communications Group formed a task force to develop specific cost reduction proposals which would improve Company productivity. These proposals defined improved engineering management techniques which would achieve a greater reduction in design deficiencies and thus improve the effectiveness of the technology. These techniques are discussed in this paper and include 1) technical practices, 2) design checklists, 3) design validation reviews, and 4) design problem summaries.

Hughes' engineering management approach establishes design authority and responsibility. Engineering guidelines, which include past design deficiencies and checklists of key development considerations, are maintained at the department level. This is an important aspect of mission assurance to ensure that mistakes are not repeated and important considerations are not missed. Designs are checked by knowledgeable specialists. New design deficiencies are identified, guidelines modified, and future designs are checked for these deficiencies. These techniques, when properly applied, should not only reduce design deficiencies, but improve the effectiveness of the technology and provide mission assurance at a reasonable cost.

Introduction

One of the major goals of Hughes Aircraft Company is to perform successfully in every aspect of the Company's business activity. At Hughes mission assurance is viewed as those techniques which enhance program success. The Hughes Space and Communications Group (SCG) Technology Division has developed some improved techniques for minimizing design deficiencies and improving engineering productivity. The effectiveness of these techniques or tasks are a key consideration in developing a cost effective mission assurance plan. Effective mission assurance tasks are those which are useful in terms of preventing the occurrence of design deficiencies or in detecting them early in the development process. A cost effective assurance plan considers the value of the tasks being performed.

Engineering deficiencies cost money. The cost of most deficiencies is a function of the time lag between the mistake and its point of detection; the most costly mistakes can be those which remain undetected until operational use. This class of deficiencies can jeopardize mission success.

A second class of engineering deficiencies may not affect mission success, but they do increase engineering cost thus lowering productivity. These are detected prior to operational use.

The following illustrates how engineering deficiencies lower productivity:

$$\text{Productivity} = \frac{\text{Number of units produced}}{\begin{pmatrix}\text{Indirect} \\ \text{and direct} \\ \text{labor used} \\ \text{to produce} \\ \text{items}\end{pmatrix} + \begin{pmatrix}\text{Rework} \\ \text{and rede-} \\ \text{sign labor} \\ \text{used to} \\ \text{correct} \\ \text{errors}\end{pmatrix}}$$

It is apparent from the above that there is a cost benefit to do business in a way such that few mistakes are created. Effective technologies are those which minimize the cost of engineering mistakes; ineffective technologies create too many mistakes and take too long to correct them.

Many attempts have been made to reduce substandard products. Some prog-

ress has been made in manufacturing through quality controls, quality circles, and screening tests. However, attempts to reduce design deficiencies through a process of design requirements including formal design reviews is not always effective. Design reviews may not consider design problems and critical design details for the following reasons:

1) Individuals performing reviews are not familiar with specific design details; consequently, they have not been able to identify costly deficiencies.

2) Design engineering may consider these formal reviews as customer relations or, in the case of company reviewers (e.g., reliability engineers), as an interference with the design process.

Design engineering, when properly executed, includes the total product requirements (i.e., conceptual design to field use). Product deficiencies indicate a breakdown in this process. Effective engineering discipline at the working level can reduce design deficiency costs.

Hughes has made an attempt to improve the effectiveness of the technology through a system of working level checks and balances administered at the engineering department level. These techniques are discussed in the paragraphs which follow.

Cost Effectiveness Task Force

In September 1976 Hughes SCG executives authorized the formation of a task force to develop specific proposals which would lead to significant reductions in SCG costs. The effort was chartered for 1 year with ten members, a manager, and an Executive Review Committee. Productivity improvements was the primary focus of the task force.

One aspect of the task force activity was a study of the institutional deficiencies which contribute to design and manufacturing errors. It was concluded that these errors result in significant cost elements. Error prevention and early detection could reduce error costs and were considered to be the general solution to this problem.

Identified Institutional Weaknesses

The task force performed an evaluation of the causes of design and manufacturing errors. It was concluded that the following general deficiencies contributed to design error costs:

1) Experience gained from past design problems was not always incorporated in new designs.

2) There was insufficient checking of designs by knowledgeable specialists.

Some design problems appear to be repetitive. For example, design errors were not always remembered. These errors were probably remembered by the senior staff and thus avoided in their designs. However, there was no effective means for transmitting the lessons learned to new personnel.

Design reviews tended to be presentations of the design to the customer and were not sufficiently effective in terms of detecting product deficiencies. The individuals performing the review were not always familiar with the specific design details; consequently, they were unable to identify and correct real deficiencies.

Another identified weakness was that there did not appear to be sufficient feedback from design and manufacturing errors. An individual who made a mistake and did not know it could conceivably continue to make the same mistakes. In addition, controls may not have been established to make sure the mistake is not repeated by others. Perhaps the weakness stems from confusion in concepts of corrective action. For example, Quality Control considers hardware rework to be adequate corrective action, and Reliability Engineering considers a design change as corrective action. However, from the error prevention standpoint, corrective action is complete when, in addition to the above corrections, the individual involved in the mistake understands the correct approach and the organization has established some form of check to ensure that this error cannot be repeated.

Based on the above assessment, the following task force objectives were identified:

1) Prevent repetitive technical problems.

2) Identify design weaknesses early in development cycle.

3) Feedback design errors to individuals who made the mistake and establish controls to ensure errors are not repeated.

Task Force Recommendations

During the period that the task force was operative, approaches which could reduce design deficiencies were examined. Specific proposals designed to correct institutional weaknesses were made to the Executive Review Committee. The task force recommended implementation of the following tasks.

1) Technical practices

- Maintain description of past design problems and the correct procedure to be followed to prevent these problems in future designs.

- Ensure new employees understand past problems and correct design procedures to be followed.

2) Design checklists

- Maintain list of key development considerations.

- Use checklist during development process to ensure important development steps are not missed.

3) Design validation reviews

- Develop plan for checking designs for deficiencies, and utilize it during development process.

- Reviews are to be performed by senior specialists.

4) Design problem summary

- Maintain list of current design problems.

- Identify correct design practice to be followed in the future.

- Take steps to prevent recurrence of design problems including issuing new technical practices, modifying checklists, and checking for deficiency during validation process.

Improving Engineering Effectiveness

Technology Division management decided to improve the effectiveness of its operation, and the task force recommendations were to be implemented at the department level.

Each department had its own approach toward reducing design errors. Working level design reviews were not always effective. Lessons learned on one program or in one department were not necessarily transmitted to others. In some instances there was insufficient learning from past mistakes. It was decided to upgrade the design error prevention and correction capability of the engineering departments.

The first step was to prepare examples of technical practices and design checklists along with sample formats. A draft of a design validation plan was prepared. One-on-one meetings were held with each laboratory manager and then with the department managers; the need for improvement was discussed at these meetings. Each department manager was requested to support the activities and to assign an individual to complete the tasks.

The next step was to meet with the individual responsible for preparing these guidelines and establish start and completion schedules. Table 1 shows the product types and disciplines that were involved in this endeavor. Although these tasks had secondary priority to the normal work load, everyone was expected to complete the tasks in a reasonable time period.

TABLE 1. TECHNOLOGY DIVISION PRODUCT TYPES AND DISCIPLINES

Communication Laboratories	T&C circuit design
RF cables	T&C test equipment
RF switches	Digital unit design
Waveguide switches	Microprocessor flight software
Ferrite devices	Controls and ground test equipment
Latching relays	Hardware
Filters	Software
Antenna	Product design
Mechanical	
Electrical	Space Vehicles Laboratories
Microwave integrated circuits	Design integration
Power supplies	Thermophysics
Power FET amplifiers	Stress
RF electrical design	Dynamics
Digital circuits	Propulsion
	Power sources
Controls and Data Systems Laboratories	Batteries
Guidance systems design	Solar arrays
Electromechanical	Power electronics

The first task was the preparation of technical practices. Technical practices are the design error memories for the departments. They were generally documented on a single sheet of paper and included the following:

- Design problem
- Design solution
- Recommended design approaches

Each department was requested to document its past problems on the above format.

Department managers, responsible for their particular product type or discipline, ensured that technical practices were maintained and properly utilized. Past problems and the correct approach were to be explained to new engineers so that problems would not be repeated. During the design validation process new designs were to be checked to ensure they were free of these deficiencies. New technical practices were to be issued as new design deficiencies were encountered thus continuing the learning process.

The next step was the preparation of design checklists. Each department was requested to prepare checklists of the key development considerations for their particular product type or discipline. A provocative question format was used. The idea was to jar the memory of the designer to make sure that he did not miss key development steps.

Because supervisors were often too busy to spend much time with their designers, the checklist would also serve as a guide and important development steps would be accomplished. As new development steps are identified, checklists are modified accordingly.

Working level design reviews were considered very important techniques for reducing design deficiencies. The reviews, as practiced, were not considered to be as effective as desired. In some instances, important engineering disciplines did not participate in the review process thus omitting important design checks.

It was decided to stress the importance of these reviews throughout the organization and department managers were given the responsibility to perform effective reviews. Secondly, it was decided that specific objectives be established for the reviews. The objectives

NUMBER	DATE	DESCRIPTION	ANALYSIS PLAN	PROBABLE CAUSE	DESIGN CHANGE	INSTITUTIONAL IMPROVEMENTS	DATE COMPLETE

FIGURE 1. DESIGN PROBLEM SUMMARY FORM

of one of the departments are as follows:

1) Greater efficiency and productivity

2) Reduction of design errors

3) Early detection of errors or deficiencies

4) Establishment of specific practices which avoid errors that have occurred (standard design procedures)

5) Reduction of cost through improved producibility

6) Analysis of the actions to cope with technical problems

7) Optimal application of resources to produce error-free designs

8) Design, integration, and testing commonality

The name "design validation" was selected so that these working level reviews would not be confused with customer reviews. The objective of the design validation review was to confirm the correctness of the design by checking it for deficiencies. Each department prepared a design validation plan and then performed its validation reviews in accordance with this plan.

The remaining technique to be implemented was a system where new design deficiencies would be identified and corrected and the design guidelines appropriately modified. As previously mentioned, it was important that the mistakes be fed back to the responsible individual so that he could learn the correct procedure and that new checks be established so that the repetition of errors could be prevented.

The Design Problem Summary Report was selected for this purpose. This report summarizes the design problems for management review. Each department is requested to document the steps it had taken to ensure that the design deficiency is not repeated. The form shown in Figure 1 is used to document this process and thus show how institutional corrective action is achieved.

An attempt has been made to develop simple and practical approaches to reduce design deficiencies. Documentation is held to a minimum so that cost effectiveness can be achieved. It is believed that the above techniques offer a practical approach to achieve a reduction in design deficiencies.

Conclusion

A primary objective of Hughes is to perform successfully in every aspect of our business activities. To achieve this, designs must have minimal deficiencies and those remaining deficiencies must be corrected early in the development process. Furthermore, we must operate effectively to ensure that our programs remain within budgets.

The Technology Division believes and the experience to date suggests that the most cost effective way to reduce design deficiencies is to make improvements at the working level. More effective working level design reviews performed by knowledgeable specialists who are familiar with

TABLE 2. PRODUCT DEFICIENCY COST REDUCTION – QUESTIONS AND ANSWERS

QUESTIONS	ANSWERS
1. Are your error costs high? • Redesign and rework costs • Warranty costs • Product liability costs	1. If answer is yes • Need to make institution improvements which will reduce these costs
2. Have you taken steps to reduce error costs? • Corporate memory of past design errors • Checklist of key design elements • Effective design review discipline – Design free of past errors – Key design elements considered – Experienced personnel evaluated design	2. If answer is no • Need to document past design errors and the correct design solutions • Need to develop design checklists so important design considerations are not missed • Need to validate designs to ensure that: – New designs are free of past errors – Checklist items are accomplished – Effective design approach is utilized
3. Are manufacturing personnel reducing defects? • Do you have quality circles?	3. If answer is no • Involve workers in solution of their defect problems
4. Do tests and inspections identify design and manufacturing weaknesses? • Qualification test • Inspection • Manufacturing test	4. If answer is no • Change tests and inspections to improve effectiveness
5. Can you identify product deficiencies from your information system? • Design errors • Manufacturing errors • Ineffective tests and inspections	5. If answer is no • Improve information system so that deficiencies can be identified in a timely manner
6. Do you have an effective system for preventing deficiencies? • Design deficiencies • Manufacturing deficiencies • Test and inspection deficiencies • Institutional deficiencies	6. If answer is no • Need effective corrective action system

design details should achieve both a better error prevention and early detection capability. Hughes believes that the mission assurance objectives can be best achieved through the use of these engineering management disciplines properly applied at the working level.

Recommendations

It is recommended that the government encourage contractors to assess the effectiveness of their technologies, identify weaknesses, and make improvements. Table 2 can be helpful in this process.

THE DESIGN REVIEW PROCESS

Presented At The
MISSION ASSURANCE CONFERENCE
Design Workshop

29 April 1980

Presented By

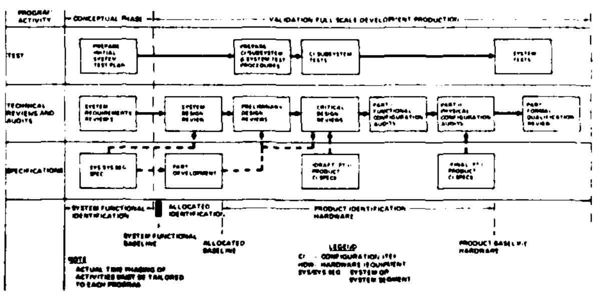
E. A. Webster
Chief Program Engineer
SGS-II Program

McDonnell Douglas Astronautics Co.
Huntington Beach, Calif.

OVERVIEW

- MIL-STD-1521A
- Perspective
- Reviews and Audits
- More Reviews and Audits
- Still More
- Cognizant Engineers
- Technology Previews
- Periodic Briefing and Reviews
- Contractor/Customer Emphasis
- Common Contractor Faults
- Common Customer Faults
- Recommendations

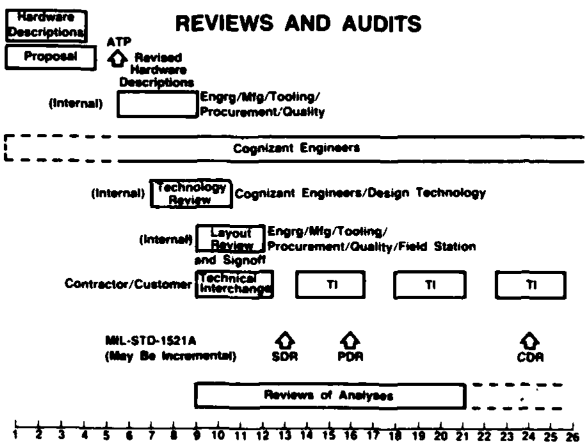
MIL-STD-1521A REVIEWS



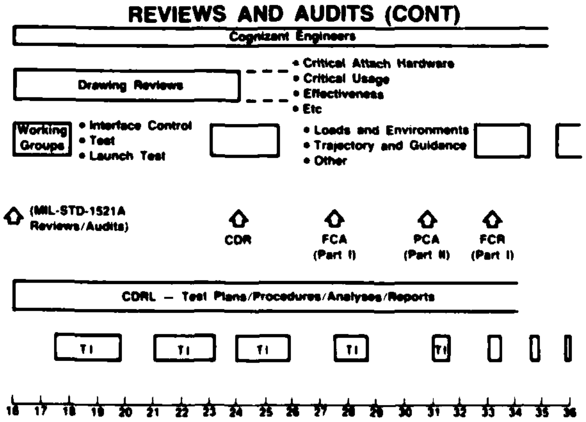
PERSPECTIVE

- Launch Vehicle Hardware
- Medium Complexity
- $10 to $50 Millions Range
- 2-Year Duration

REVIEWS AND AUDITS



REVIEWS AND AUDITS (CONT)



MORE REVIEWS/AUDITS

- System Effectiveness Audits
  - Reliability
  - Maintainability
  - Human Engineering
  - Corrosion Control
  - Etc
- Parts — Materials — Processes Control Board (PMPCB)
- Range Safety Reviews
- Explosives Hazards Review
- Telemetry Frequency Allocation Review
- Safety Reviews
- Quality Audits
- Award Fee Evaluations

STILL MORE REVIEWS

- Independent Readiness Reviews
  - Customer Heavyweights
  - Considerable Depth — Good Audit Procedure
- Vehicle Flight Readiness Review
  - Moderate Preparation
  - Formal Presentations
  - Executive Overview

COGNIZANT ENGINEERS*

Chief Program Engineer

- ELECTRONICS
  - Telemetry
  - Elec/Electronics
- MECHANICAL
  - Ordnance
  - Separation
- STRUCTURAL
  - Design
  - Strength
  - Weights
  - Vibration, Shock, Acoustics
- PROPULSION
  - Motor
  - Spin System
- SYSTEM PERFORMANCE
  - Trajectory
  - Stability/Control
- EFFECTIVENESS
  - Reliability
  - Maintainability
  - Safety
- TEST
  - Development
  - Qualification
  - Acceptance
  - In-House
  - Vendor

*Shown for a Particular Program – Others Will Differ. Larger Program Cognizant Engineers Are Usually Product Oriented.

HARDWARE DESCRIPTIONS

- Similar to Part Number ____________
- How Many — Vehicle ________ GSE ________ Spares ________
- Estimated Cost
- Availability
- Number and Complexity of Drawings
- Make/Buy Recommendation
- Next Assembly
- Sketches

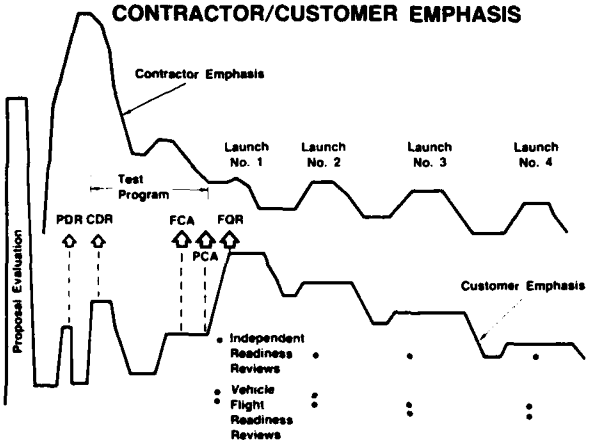
TECHNOLOGY PREVIEWS

- Cognizant Engineer Reviews System
- Senior Staff and Designers Critique
- Design Review Agreements (DRA's) Result
  - Originated by Prime Technology
  - Signoffs by Interfacing Technologies
- DRA's Widely Distributed
  - Quality
  - Manufacturing
  - Tooling
  - Procurement
  - Design Technologies
  - Test Laboratories
  - Field Station

PERIODIC BRIEFINGS AND REVIEWS

- Three-Times Weekly Engineering Review
  - Informal Round-table Style
  - Program Engineer Moderates
  - Cognizant Engineers Discuss
  - Early Surfacing of Problems
  - Direct Assignment of Tasks/Responsibilities
  - 1/2-Hour Maximum
- Weekly Program Review
  - Viewgraph Presentations
  - Program Manager
  - Department Heads (Engineering, Manufacturing, Procurement, Quality, Fiscal, Etc.) Discuss
  - Direct Feedback on Problem Areas
  - 1-2 Hours Maximum
- Monthly Executive Reviews (30-30)
  - Senior Executive Present Moderates
  - Program Managers Discuss
  - 1/2-Hour Maximum Per Program

CONTRACTOR/CUSTOMER EMPHASIS



COMMON CONTRACTOR FAULTS

- Lack of Candidness
- Evasiveness
- Lack of Preparation
- Customers Competence Underestimated
- Lack of Money (Did Not Bid Enough to Cover Reviews, and Certainly Not Enough to Cover Action Items)
- Too:
  - Elaborate — Long
  - Boring — Short
- Not Enough Substance
- Not Well Organized
- No Effective Exchange With Customer's Technical People

COMMON CUSTOMER FAULTS

- Often Inflexible
- Usually Sends Too Many Attendees
- Action Items Often Trivial. Many Questions Adequately Answered During Review End Up as "Action Items"
- Some Attendees Appear to Want (or Need) Tutoring
- Technical Emphasis Not Well Balanced
- Frequently Wants More Than He Paid For
- Frequently Late
  - For Review
  - With Comments
  - With Reaction to Action Items

RECOMMENDATIONS

- Involve Customer Technical Experts In Early Contractor Review Processes
- Place More Emphasis on Technical Interchange (T.I.) Meetings – Less On Large-Scale Reviews
- Revise MIL-STD-1521A To Include TI's and Working Groups

DESIGN REVIEW "ESCAPES"

An examination of some "escapes" from the design review process, in the hope of sealing off a few of the cracks that things have been known to fall through.

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Reliability and System Satety Department
TRW - Defense and Space Systems Group
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A review of the kind, and causes, of expensive escapes from our design review process has led me to an awareness about at least one shortcoming of the process, one which I think deserves some attention.

In the few minutes I have for this presentation, a few case histories will help set the stage. Then I'd like to discuss ways to prevent these escapes with you.

THE PROBLEM:

During test, short circuits developed between copper circuit traces on, and mounting bolts through, a multi-layer PC board.

THE CAUSE:

The board layout did not leave enough clearance between traces and mounting bolts.

WHAT WENT WRONG:

These boards were reviewed by reliability engineers to study the physical relationships between circuit traces and piece parts. In order to clearly see the traces in the board, transparencies of the copper artwork were layed one atop the other and viewed through the light.

But the transparencies showed only the copper artwork, not the position of holes for the mounting bolts.

EXAMPLE

- PROBLEM: High-voltage arcing.
- CAUSE: Inadequate spacing between elements. During potting, the part's terminal board was not held firm, but was allowed to find its own position as determined by stresses on connecting wires. This resulted in random spacing between components.
- FIX: Some terminal boards were affected; others were not. Expensive testing and reword were needed to find affected parts, unpot them, repair with a new holding fixture, and retest the units.
- COMMENTS: All tolerance and manufacturing fixtures should be reviewed by Quality and Manufacturing at unit level design reviews.

EXAMPLE

- PROBLEM: Improper functioning of an op-amp in a voltage regulator circuit.
- CAUSE: The part was mis-applied, under a combination of conditions — high temperature, low input voltage and output characteristics of the op-amp.
- FIX: Re-screen all op-amps and selectively pick those with special performance characterisitics. Replace all op-amps in flight units with specially screened devices, and retest.
- COMMENTS: A more thorough review of worst case assumptions by reliability, and of part applications by Components and design engineers, may have uncovered this problem at the Intermediate Design Review.

EXAMPLE

- PROBLEM: Unable to maintain required gyro temperature.
- CAUSE: Heat loss greater than assumed in thermal analysis of heat loss paths.
- FIX: Redesign and repair all flight units.
- COMMENTS: A more critical review of the thermal design assumptions would have uncovered this problem at the Critical Design Review.

EXAMPLE

- PROBLEM: Switch would not actuate properly.
- CAUSE: Lead wires broke in vibration test. Resulted from poor product engineering. Insufficient strain-relief on connector wires.
- FIX: Redesign and rework already-built/tested units.
- COMMENTS: An assembly drawing review by reliability engineers would have prevented this problem.

EXAMPLE

- PROBLEM: Cracks and delamination occurred in a solar panel structure, following cold-soaking of the panel.
- CAUSE: Erroneous assumptions (regarding thermal expansion coefficients) led to under-estimating the degree of flexing that would occur with thermal cycling.
- COST: Redesign, rebuild, retest, schedule slip.
- COMMENTS: A more thorough review of modeling assumption in a thermal subsystem or a solar array review should have uncovered this problem before building the solar array.

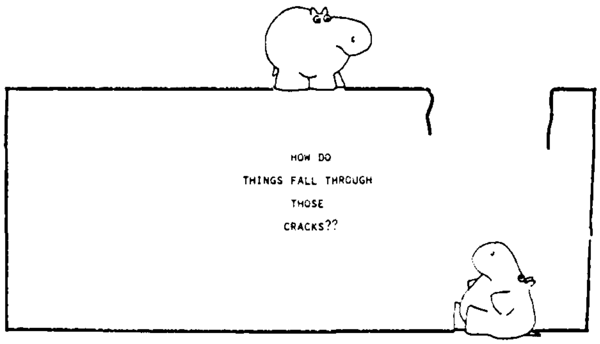
I'm sure we all have an assortment of war stories to tell. And no wonder; think of the incredibly complex equipment we build. In every one of our designs, there are a million nooks and crannies where gremlins can hide out, lieing there like so many spring-loaded booby traps wanting to go off in our faces (just when we think we've made it safely through the pass!)

Behind each analysis and every decision we make, there are defects in our design process itself: Simplifying assumptions; erroneous, inaccurate and uncertain data; insufficient attention to details; lack of historical perspective by new people; just

plain goofs; and cracks for things to fall through.

After we've eradicated a million gremlins, the million-and-one-th gremlin is still lurking in the shadows, waiting to ambush us.

Time is the real culprit. We've got deadlines to meet, decisions to make, schedules to hold and budgets to save. We do our best, but we're only human.



Design Reviews are supposed to catch these things for us.

Sure enough, all the appropriate words get said in all the appropriate sections of MIL-STD-1521, and in every reliability and systems engineering program plan ever written - Thou shalt review assumptions, data sources, analytical methods, etc. And indeed, we try to. But again, Time is the culprit.

A typical design review agenda lays aside a (relatively) few minutes to dozens of topics deemed important to the hardware being reviewed that day - electrical properties, specifications, EMC, vulnerability, reliability, environment, interfaces, power consumption, testability, manufacturability, you name it.

The room fills with engineers, managers, support troops, customers, on-lookers, advisors and critics. A Responsibile Engineer gives an explanation (and some times a defense) of the results of his analyses, a few probing questions are asked, an action item or two is taken, and the next presenter comes to the podium.

If a presenter takes too long - if too many probing questions are asked, or too many axes get ground - the agenda falls behind, the audience gets fidgety and five o'clock draws near.

The problem, I think, is that we don't give enough time to reviewing the integrity of the process the design went through along the way to the Design Review itself.

WHY DESIGN REVIEWS MISS THESE THINGS ...

- DESIGN REVIEWS TEND TO FOCUS THEMSELVES ON THE *DESIGN* ...
    - Not on the *processes leading up to the design* ...
    - In spite of what it says in Program Plans and Mil Standards ...
    - There just isn't enough time that can be allotted for each subject in a design review.
- SO, THESE THINGS TEND TO GET NEGLECTED ...
    - A critical and thorough examination of all assumptions ...
    - The quality of the underlying data itself . .
    - Analytical tools and techniques used ...
    - Missing data, simplifications and approximations ...
    - Up-to-date-ness of drawings, etc., from which work is done ...
    - Experience and qualifications (by name) of individuals doing the work.

For lack of a better phrase, I've coined my proposal ASSUMPTIONS REVIEWS, though the title is a little misleading and confining.

I propose that all major design reviews be preceeded by a series of Assumptions Reviews which are exempt from passing judgement on the design itself. Rather, these review should be charged with examining the assumptions, techniques and qualifications that underly the results will be presented at later design reviews.

I propose that these Assumptions Reviews be formatted in the same way as normal design reviews - complete with a committee, a chairman, data packages (describing assumptions, etc.), action items and formal closeout. Such a review's sole charter is to assure the later Design Review's chairman that the underpinnings and thoroughness of the analyses leading to the presented design are sound and trustworthy.

I believe that each of several disciplines ought to have dedicated Assumptions Reviews - for example, reliability, thermal, vibration, etc. - so that time, attention and talent is not diluted from the review at hand, and that each review ought to be across-the-entire discipline as it applies to the project (ie., not focused on, say, the reliability analyses of just one subsystem.)

A PROPOSAL FOR "ASSUMPTIONS REVIEWS"

- REQUIRE FORMAL PRE-REVIEWS ...
  - Structured like design reviews — agenda, data packages, committees, action items, closeout, etc.
  - Focus on the *integrity* of the analytical processes the design went through.
  - Focus on those issues on the preceeding slide, not on the design itself. This is not a dry run of the design review coming up later.
  - Separate reviews for separate issues — one for reliability assumptions, another for thermal assumptions, a third one for *vibration assumptions, etc.*
- THEN AT THE FORMAL DESIGN REVIEWS WE NOW NORMALLY HOLD ...
  - Chairmen of the Assumptions Reviews should report to the committee on his findings in that review.
  - Assure the committee that the underlying processes the design went through are trustworthy.

DESIGNING FOR MISSION ASSURANCE

DESIGN WORKSHOP

MANNED MANEUVERING UNIT SPACE OPERATIONS SIMULATION DESIGN REVIEW PROCESS

Leroy J. Ducharme
Section Manager
Systems Integration

MISSION ASSURANCE – DESIGN WORKSHOP

Designing For The Shuttle Era

The Design Review Process

System Design Process:

Hardware/Software/Man-Machine Interface

• Conceptual Phase	- Functional Baseline	- System Requirements Review
• Definition Phase	- Allocated Baseline	- System Design Review
• Development Phase	- Preliminary Design	- Preliminary Design Review
	- Detail Design	- Critical Design Review
	- Build, Code, Test	- Test Readiness Review
	- System Verification	- Configuration Audits
• Integration Phase	- System Validation	- Preliminary Qualification Test
		- Final Qualification Test
	- System Certification	- Certification Board Approval
• Operations Phase	- Change Orders	- Configuration Review

THE DESIGN REVIEW PROCESS

Military Standard 1521A, Technical Reviews and Audits for Systems, Equipments, and Computer Programs identifies the design reviews to be conducted during the life cycle of a program. In addition to identifying the design review process, it is important to define the phase of the program in which the review/audit is conducted and the objective achieved in support of the hardware/software/man-machine interface.

The Manned Maneuvering Unit Program, Space Operations Simulation (SOS) and Astronaut training, was selected to demonstrate the application of MIL-STD-1521A in a laboratory environment. The contract with NASA requires that the SOS facility be demonstrated and certified prior to astronaut training.

MISSION ASSURANCE – DESIGN WORKSHOP

The Design Review Process

Manned Maneuvering Unit Program
- Space Operations Simulation And Training
- Objectives: Design Verification And Astronaut Training

Conceptual Phase - Functional Baseline - SRR - System Requirements Review

- SOW Requirements
  High Fidelity Simulation - 6 Degrees Of Freedom - Safety Certified
  Shirtsleeve And Suited Operation
  Credible Malfunction Capability
  Simulation Data To Be Recorded (Communications And Video)
  Recovery To Limited Capability In 3 Days
- Derived Requirements
  Performance (MMU Mission - Tile Inspection And Repair)
  Structures (Stress And Loads Analysis)
  Safety (Mockups, Design, Operations)
  Overall System - HW/SW/MMI
- SRR - System Specification ("A" Level Specification)
  Trade Study Reports, Functional Flows,
  Operations Concept

CONCEPTUAL PHASE

The Manned Maneuvering Unit program, Space Operations Simulation and Training portion of the contract has two primary objectives: design verification and astronaut training.

The simulation requires six degrees of freedom to provide astronaut training, must be capable of supporting both shirtsleeve and suited operation, and must provide the capability to impose credible malfunctions to ensure proficiency training. The simulation facility must be safety certified, have the capability to record all video and communications during the training process, and be designed to recover from a malfunction in three days.

Derived requirements were identified in support of performance, structures, safety and overall system performance. Safety considerations were applicable to mockups, design criteria and MMU operations. The System Requirements Review provides an opportunity to present the results of trade studies, functional flows and the proposed operations concept. User concurrence is vital to the success of the program and is documented in an "A" level specification.

MISSION ASSURANCE - DESIGN WORKSHOP

The Design Review Process

Definition Phase - Allocated Baseline - SDR - System Design Review

- Hardware
  - 6 Degree Of Freedom Carriage
  - Mockups
  - Manned Maneuvering Unit
  - Test Conductor/Run Coordinator Console (TC/RC)
  - Space Operations Simulation Console
  - Communications And Video System
  - Safety Equipment
- Software
  - MMU Performance Equations
  - Orbiter Dynamics
  - Contingency (Malfunction Procedures)
  - Display Formats To TC/RC
  - Safety Parameters
- Man-Machine Interface
  - Astronaut - MMU
  - Test Conductor And Run Coordinator
  - SOS Console Operator
  - Safety Monitor
- SDR
  - Simulation Implementation Plan (Preliminary System Description And Allocation Doc.)
  - Preliminary Configuration Item - Development Specification (B1)
  - Software Requirements Document (B5 Specification)

DEFINITION PHASE

The definition phase results in an allocation of requirements to hardware, software, and the man-machine interface and is presented at the System Design Review (SDR).

The SDR presents an opportunity to define the proposed allocation of requirements and is documented in "B" level specifications: B1 specification for hardware configuration items and a B5 specification for software requirements. The MMU Space Operations Simulation also required a Simulation Implementation Plan to define the Man-Machine interface and program milestones.

Definition of the Test Conductor, Run Coordinator, SOS Console Operator, and the Safety Monitor roles and responsibilities were presented at the SDR to obtain user concurrence.

MISSION ASSURANCE - DESIGN WORKSHOP

The Design Review Process

Development Phase - PDR And CDR

- Hardware
  - Subsystem Analyses And Trade Study Results
  - Performance Data
  - Math Models (Computer Interface Electronics)
  - Drawings And Procurement Specifications (C1-Build To)
  - Test Specification
- Software
  - Subsystem Analyses And Trade Study Results
  - Functional Diagrams And Functional Decomposition
  - Data Base Analysis
  - Software System Partitioning
  - Computer Program Product Specification (C5-Code To)
  - Test Plans And Procedures
- Man-Machine
  - Personnel Subsystem Analysis
  - Human Factors Analysis
  - Certification Plan
  - Training Plan
  - Safety Analysis Review And Hazard Analysis Sheets

DEVELOPMENT PHASE

The development phase consists of two design reviews, preliminary and critical, a test readiness review and configuration audits. These major milestones cover hardware, software and man-machine interfaces.

Hardware elements are presented via subsystem analyses, trade study results, performance data, math models and are documented in C1 specifications, covering both build to and test procedures. Software elements are presented via functional diagrams and decomposition, data base analysis, system partitioning and are documented in C5 specifications, covering both code to and test procedures.

The man-machine considerations are presented via personnel subsystem analysis, human factors analysis and are documented in certification and training plans, including a safety assessment via hazard analysis sheets.

MISSION ASSURANCE-DESIGN WORKSHOP

The Design Review Process

Development Phase

- Build-Code-Test - TRR - Test Readiness Review
  - Hardware: Fabrication - Subassembly Tests - Qualification - Subsystem Integ. Test
  - Software: Code - Unit Test - Module Test - Subsystem Integ. Test
- System Verification - FCA - Final Configuration Audit
  - HW/SW/MMI: Physical And Functional Audit - Against "A" Spec.
  - Verification Matrix - Analysis, Test, Inspection
  - Requirement Verification - B1/B5 vs. C1/C5
  - Through Put Verification - Commands And Response
  - Positional/System Training - TC/RC/SOS/Safety
  - Evaluate Reports - Structures, Stress, Safety
  - Procedures (Validation And Operational) - Review

DEVELOPMENT PHASE - Continued

The test readiness review is conducted for both hardware and software elements. The qualification of hardware and the module testing of software are reviewed in preparation for integrated testing at the subsystem level.

A final configuration audit is performed, both a physical and functional audit, to verify design conformance against the "A" specification; the verification may be performed by analysis, test, or inspection.

The MMU SOS system verification will consist of through put, commands and response,

training and certification of all console positions, a safety audit and a review of validation and operational procedures.

MISSION ASSURANCE – DESIGN WORKSHOP

The Design Review Process

Integration Phase - System Validation - FQT - Final Qualification Test

Mission Simulation

- Unmanned Test And Checkout - PQT
- Manned Test And Checkout (Shirtsleeve And Suited) - FQT
- Certification Board Approval
- Customer Demonstration And Acceptance

Operations Phase

- Training - Normal And Contingency
- Change Orders - Added Capabilities And Enhancements
- Discrepancy Reports
  - Class I - Certification Board Approval
  - Class II - Safety Approval
  - Class III- Test Conductor Approval
- Configuration Management - Change Board Activities
  Technical And Programmatic Assessment

INTEGRATION PHASE

The Integration phase consists of system validation and system certification. The MMU preliminary qualification test will consist of an unmanned test and checkout of the six degree of simulation hardware and the software programs. Certification board approval will be granted after unmanned and manned demonstration against approved procedures. Customer acceptance will be granted after a demonstration of the total mission simulation, including malfunction and recovery capabilities.

OPERATIONS PHASE

Astronaut participation will consist of MMU proficiency training to perform a tile inspection and tile repair mission, including normal and contingency procedures. Change orders will be processed to add capabilities and enhancements; discrepancy reports will be utilized to perform troubleshooting and repair. Three classes of changes have been defined to allow proper approval prior to continued operations.

MISSION ASSURANCE – DESIGN WORKSHOP

Key Issues

- System Requirements Review
  User Concurrence
- Preliminary Design Review
  Design To Cost/Life Cycle Cost Consideration
- *Configuration Audits*
  Firm Baseline - Documented

Recommendation

The Design Review Process Should Stress The Role Of Systems Engineering And User Concurrence At All Steps Of The System Design Process.

KEY ISSUES

At each phase of the program, user concurrence is required and is vital to mission success. The system requirements review, conducted during the conceptual phase, is one of the most important milestones in the design review process.

The life cycle cost or design to cost critical requirement for cost data is at the preliminary design review: if several design options are presented, cost considerations play a vital discrimination role.

Configuration audits are vital to ensure a firm baseline, properly documented. A physical and functional audit for hardware, software and man-machine interfaces to verify "A" specification compliance is mandatory.

RECOMMENDATION

The design review process should stress the role of systems engineering and user concurrence at all steps of the system design process.

DESIGNING FOR MISSION ASSURANCE

MISSION SUCCESS THROUGH THE EARLY DETECTION OF POTENTIAL FAILURES VIA THE "PRINCIPAL ENGINEER" CONCEPT

BY
CHARLES BIERMAN

FIVE-YEAR RECORD

This success record is in a large measure attributed to the "principal engineer" concept and formal review process. The "principal engineers" are top system designers and analysts. The purpose of the review process is to provide maximum assurance that the launch vehicle/spacecraft/software/GSE at critical schedule points are free of problems, mistakes, or potential failures. The principal engineers are the key "investigators" who report their findings to meetings of joint government-contractor management.

FIVE-YEAR RECORD

39 SUCCESSFUL SPACE MISSIONS

17 ATLAS/CENTAUR	17 ATLAS	5 TITAN/CENTAUR
2 PIONEER VENUS	6 GPS	2 VIKING
3 HEAO	1 P78-1	2 VOYAGER
3 FLTSATCOM	1 TIROS	1 HELIOS
3 COMSTAR	1 SEASAT	
6 INTELSAT	1 NOAA-A	
	7 MISC.	

1 UNSUCCESSFUL ATLAS/CENTAUR (INTELSAT) IN 1977

PRIMARY CAUSES

MARGINAL DESIGNS

Can be rectified by better design reviews and adequate qualification level testing.

"INNOCENT" CHANGES

The full impact of the change on the system or other systems is not fully evaluated or tested.

INADEQUATE TESTING

Didn't test something you could have tested. The space system must work perfectly the first time. Thorough checkout of hardware and software is mandatory. Testing must be thorough enough to detect marginal designs during qualification and system performance prior to launch.

INADEQUATE REVIEW OF DATA

The data was trying to tell you something. Too often flight failures cause a re-review of test data that had a message which was ignored or overlooked.

POOR QUALITY AND WORKMANSHIP

The only failure in the past five years falls in this category. Constant effort is required to maintain quality standards.

PRIMARY CAUSES OF A MISSION FAILURE IN ANY PROGRAM

PREMISE: NO ONE WANTS TO MAKE AN ERROR. HOWEVER, FAILURES CAN OCCUR BECAUSE OF UNDETECTED PROBLEMS OR MISTAKES MADE IN THE FOLLOWING AREAS:

- MARGINAL DESIGNS INADEQUATELY PROOFED AND QUALIFIED
- "INNOCENT" DESIGN/SOFTWARE CHANGES
- INADEQUATE READINESS TESTING
- INADEQUATE REVIEW OF TEST DATA
- POOR QUALITY AND WORKMANSHIP

FINDING MISTAKES

A positive attitude by both government and contractor management is of vital importance in the problem resolution cycle. Good managers should encourage the engineers in discovering any mistakes and help them gather resources necessary to correct the problems.

Engineers, assemblers, technicians, etc., are all human and can make mistakes. We must promote the attitude in all participants to be constantly alert to weaknesses and potential failures. All people involved should be encouranged to come forth with their worries, problems, or goofs without fear of reprisal, etc.

FINDING MISTAKES, PROBLEMS, OR POTENTIAL FAILURES

- POSITIVE APPROACH – MANAGEMENT AND GOVERNMENT
  - HUMANS DO MAKE MISTAKES
  - ENCOURAGE PEOPLE TO RECOGNIZE AND ADMIT THEIR OWN MISTAKES IN A TIMELY FASHION
  - COMMEND THOSE WHO DISCOVER MISTAKES OR POTENTIAL FAILURES
  - NO PENALTIES OR REPRISALS FOR THOSE WHO MAKE A MISTAKE
  - WHOLEHEARTED MANAGEMENT SUPPORT IN CORRECTING MISTAKES
- REPRISAL APPROACH IS NEGATIVE
  - MISTAKES CAN GO UNREPORTED
  - MISTAKES MAY BE COVERED UP
  - MISTAKES MAY NOT BE DISCOVERED IN TIME

PRINCIPAL ENGINEER CONCEPT

Outstanding designers/analysts are selected to fill the roles of principal engineers. They must be of a caliber whose judgment and recommendations you respect, whom you are proud to have on your team, and who act as an extension of yourself.

PRINCIPAL ENGINEER CONCEPT

- QUALIFICATIONS
  - TOP DESIGNERS/ANALYSTS
  - HIGH IN INITIATIVE, INTEGRITY, AND TEAM SPIRIT
  - RESPECTED BY PEERS, MANAGEMENT, AND GOVERNMENT
- RESPONSIBILITIES
  - ALERTNESS TO SYSTEM/COMPONENT/SOFTWARE WEAKNESSES
  - SUPPORT PROBLEM INVESTIGATION DURING MANUFACTURE, TEST, AND LAUNCH
  - PROVIDE RECOMMENDATIONS FOR PROBLEM RESOLUTION
  - SUPPORT FORMAL/INFORMAL REVIEW PROCESSES

MANAGEMENT SUPPORT OF PRINCIPAL ENGINEERS

- MANAGEMENT'S NURTURING OF THE PRINCIPAL ENGINEER CONCEPT BY LISTENING TO HIS RECOMMENDATIONS AND JUDGMENTS PRIOR TO MAKING A CRITICAL DECISION IS THE KEYSTONE OF A SUCCESSFUL PROGRAM.
- MANAGEMENT'S REACTION TO TIMELY REPORTED ERRORS SHOULD BE CHARACTERIZED BY GRATITUDE AND ASSISTANCE IN RESOLUTION, NOT OF REPRISAL AND FINGER POINTING.
- THE PRINCIPAL ENGINEER, BY MANAGEMENT'S ACTION, KNOWS HE IS BEING HELD RESPONSIBLE FOR HIS HARDWARE. HIS OWN PRIDE WILL ASSURE HE IS NOT EMBARRASSED BY ANY POOR DESIGN, HARDWARE FAILURE, OR A SCHEDULE DELAY.
- MANAGEMENT MUST BACK UP THE PRINCIPAL ENGINEER'S ROLE IN RESOLVING POTENTIAL FAILURES AND CORRECTING MISTAKES (REGARDLESS OF WHO MADE THEM).

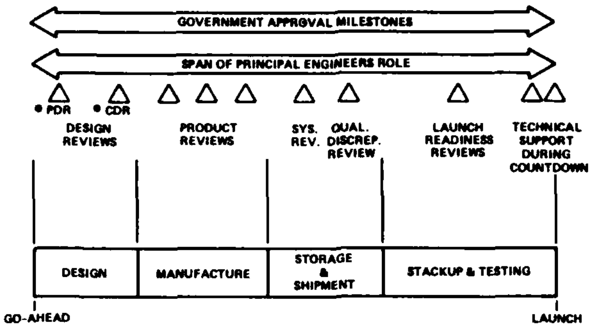
REVIEW CYCLE

A planned and funded program of reviews involves the government and the principal engineers at each major step of space system development from concept through launch.

The following photos show the review process in action.

These planned reviews are supplemented by problem solving review boards which meet as required. The principal engineer is usually the key participant in these reviews.

FORMAL REVIEW PROCESS



* PRESENTLY DEFINED IN MIL-STD-1521A

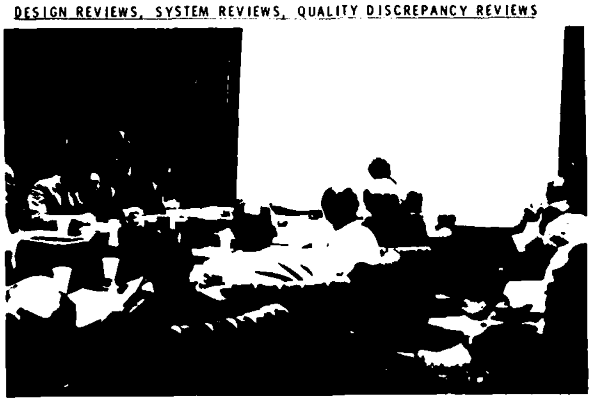
DESIGN REVIEWS, SYSTEMS REVIEWS, QUALITY DISCREPANCY REVIEWS

These milestone formal reviews are conducted as joint government-contractor meetings. SPDRs, PDRs, and CDRs are defined review milestones from MIL-STD-1521A.

The objective of Systems Reviews is to ensure than the launch vehicle is configured to satisfy mission requirements. All mission analysis, subsystem hardware design, and software design are assessed for compatibility with each other and the current mission definitions.

The objective of the Quality Discrepancy Reviews is to assure the integrity of flight hardware by a review of quality discrepancy dispositions.

DESIGN REVIEWS, SYSTEM REVIEWS, QUALITY DISCREPANCY REVIEWS



FACTORY PRODUCT REVIEWS

Following the release of drawings, the procurement/production/testing cycle begins. This is where weaknesses in the design and manufacturing errors surface.

So we get the principal engineers directly involved in the manufacturing/testing cycle. Their formal approval at key assembly points must be obtained before work may continue. The final review is the completed launch vehicle.

Review sequence:

1. Quality Control Inspection
2. Principal Engineer Review
3. Government (DCAS) Review

FACTORY PRODUCT REVIEW

LAUNCH READINESS REVIEW AT THE LAUNCH SITE

SITE REVIEW "TEAM" CONSISTS OF:

1. Government (plus consultants)
2. Principal Engineers
3. Launch Site Engineers
4. Associate Contractors

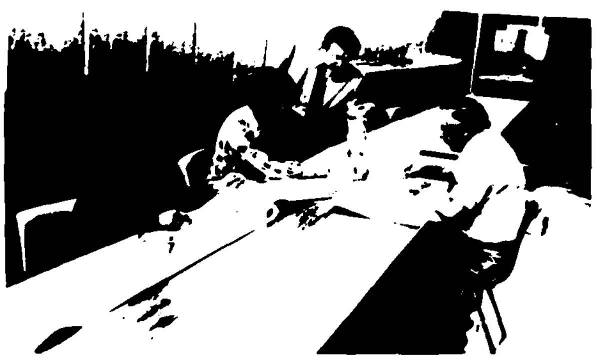
REVIEW ITEMS:

1. Walkdown
2. Data
3. Procedure History Data
4. Site Configuration Control Paper
5. Quality Assurance Records

REVIEW RESULTS:

The results of this review are presented to Government, Convair, and associate contractor management.

LAUNCH READINESS REVIEW



LAUNCH SUPPORT TEAM

AGAIN THE "TEAM" IS COMPOSED OF:

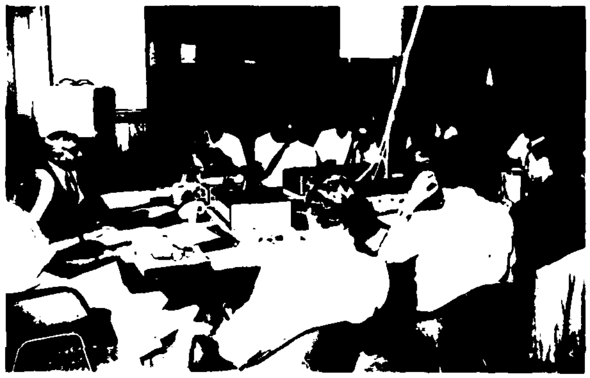
1. Government (plus consultants)
2. Principal Engineers
3. Launch Site Engineers
4. Associate Contractors

After years of work, success can be determined by the few hours of countdown and booster flight. If all responsible parties, including the principal engineers, have done their job well, success is greatly enhanced.

In this photo, the team is monitoring the countdown event. They are ready to help resolve problems that arise during the countdown.

T-5 MINUTES AND COUNTING
ALL SYSTEMS "GO"

LAUNCH SUPPORT TEAM T-5 MIN AND COUNTING



CONCLUSIONS AND RECOMMENDATIONS

Use of the approaches presented has been a key element in the successful record achieved on space programs contracted by Convair.

These and similar approaches are used in other programs.

For space applications, the principal engineer concept can be a powerful tool for increasing launch success probability.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

- THE PRINCIPAL ENGINEER CONCEPT AND THE REVIEW PROCESSES SHOWN BELOW ARE NOT NOW IN MIL-STD-1521A (USAF).
- THEIR INCLUSION WOULD BENEFIT THE GOVERNMENT:
  - IMPROVED VISIBILITY AS TO MISSION READINESS
  - REAL TIME INVOLVEMENT IN ACTION ITEM DECISIONS
  - MUCH INCREASED PROBABILITY OF MISSION SUCCESS

RECOMMENDATIONS

- IMPLEMENT THE PRINCIPAL ENGINEER CONCEPT AND I[illegible]DE IN THE MILITARY STANDARD AS NORMAL PROCESSES FOR SPACE PROGRAM[illegible]
  - FACTORY PRODUCT REVIEWS
  - SYSTEMS REVIEWS
  - QUALITY DISCREPANCIES REVIEWS
  - LAUNCH SITE PRODUCT & READINESS REVIEWS
- RECOGNIZE THE FUNDING REQUIREMENTS TO ACCOMPLISH THESE REVIEWS.

DESIGNING FOR THE SHUTTLE ERA. INTRODUCTION AND OVERVIEW BY THE SUB-GROUP CHAIRMEN

J.B. Sterett
Marshall Space Flight Center
NASA

AGENDA

DESIGN WORKSHOP - "DESIGNING FOR SHUTTLE ERA"

INTRODUCTION	J. STERETT, NASA/MSFC
o WORKSHOP APPROACH o KEY ISSUES/DISCUSSION TOPICS o WORKSHOP "MODUS OPERANDI"	
DESIGN REQUIREMENTS	L. WILLIAMS, NASA/JSC B. WAGNER, AEROSPACE
o HOW DEFINED/CONTROLLED o HOW GOVERNMENT EXPECTS REQUIREMENTS UTILIZED o CONCERNS	
CONTRACTOR VIEWS RELATIVE TO DISCUSSION TOPICS	
o ORBITER	H. EMIGH, ROCKWELL
o IUS BOOSTER	J. ECKLE, BOEING
o SPACE TELESCOPE	M. MERCER, LOCKHEED
o CARGO INTEGRATION	P. CHRISTENSEN, MARTIN
DISCUSSION	J. STERETT, NASA/MSFC
o REDEFINE ISSUES o SUMMARIZE POSITIONS o DISCUSS DIFFERENCES o SUMMARIZE RECOMMENDATIONS	
SPLINTER MEETINGS	
o ACTIVATED IF MORE TIME NEEDED TO WORK RECOMMENDATIONS.	

DESIGNING FOR THE SHUTTLE ERA MISSION ASSURANCE

- INCLUDES CONSIDERATIONS OF PAYLOAD WEIGHT, COST, AND SCHEDULE AS WELL AS FUNCTIONAL PERFORMANCE

SHUTTLE ERA "UNIQUE" DESIGN CONSIDERATIONS

- SHUTTLE ELEMENTS DESIGNED AND TESTED CONCURRENTLY WITH DESIGN AND TESTING OF VARIOUS PAYLOADS
- PAYLOADS REQUIRED TO DESIGN FOR ORBITER LANDING LOAD CONDITIONS
- SHUTTLE PROVIDES SERVICING, REPAIR, AND RECAPTURE OF PAYLOADS IN EARTH ORBIT

WORKSHOP MODUS OPERANDI

O QUESTIONS TO SPEAKERS PERMITTED FOR UNDERSTANDING OR CLARIFICATIONS

O SPEAKERS WILL PARTICIPATE AS RESPONDERS TO QUESTIONS/COMMENTS

O DISCUSSION PERIOD QUESTIONS/COMMENTS FROM WORKSHOP AUDIENCE IN WRITING

O NOT A SHUTTLE/ORBITER PROGRAM REVIEW

"DESIGNING FOR THE SHUTTLE ERA"

J. B. STERETT

THEME: ASSURING MISSION SUCCESS IN DESIGNING FOR TRANSPORT ON THE SHUTTLE.

KEY DISCUSSION TOPICS

1. STRUCTURAL DESIGN REQUIREMENTS

   LOADS ARE CHANGING - TIMELINESS OF INFORMATION - HOW MUCH CONSERVATISM IS BEING DESIGNED IN? - IS IT REALISTIC? - IS IT IMPACTING MISSION ASSURANCE?

2. PREDICTED ENVIRONMENTS - (ACOUSTICS/VIBRATION/THERMAL, ETC.)

   CHANGING REQUIREMENTS - TIMELINESS OF INFORMATION - DATA FLOW AND INTERCHANGE - HOW CONSERVATIVE ARE THE REQUIREMENTS? - HOW MUCH CONSERVATISM IS BEING DESIGNED INTO THE HARDWARE? MISSION ASSURANCE IMPACTS?

3. MEASURED ENVIRONMENTS

   WHEN AND TO WHAT EXTENT WILL THE SHUTTLE FLIGHT ENVIRONMENT RESPONSE BE MEASURED? WHAT IS THE PLAN TO DISSEMINATE THE RESULTS TO THE PAYLOAD DESIGNERS? HOW WILL THE DATA BE USED BY THE PAYLOAD DESIGNERS? AFFECTS ON MISSION ASSURANCE?

4. DIFFERENCES IN AF AND NASA SPECIFICATIONS, DESIGN CONSTRAINTS AND DESIGN PHILOSOPHY

   IS THIS GENERATING PROBLEMS AND WHAT IS THE IMPACT ON MISSION SUCCESS? ARE WE ACHIEVING MISSION ASSURANCE WITH THE SPECIFICATIONS THAT WE ARE USING TODAY? RECOMMENDATIONS FOR CHANGES?

5. SAFETY REQUIREMENTS

   WHAT IS THE IMPACT ON DESIGN? HOW WILL INTERAGENCY APPROVAL AND CERTIFICATION BE OBTAINED?

6. MULTIPLE PAYLOAD CARGO

   INTERACTION OF PAYLOADS AND IMPACT ON MISSION ASSURANCE.

7. REUSEABILITY REQUIREMENTS

   IMPACTS ON DESIGN FOR MULTIPLE MISSIONS - ARE REQUIREMENTS WELL DEFINED (MIL-STD-1540?)? IMPACTS ON MISSION ASSURANCE?

DESIGNING FOR THE SHUTTLE ERA

PAYLOAD REQUIREMENTS DEFINITION AND IMPLEMENTATION

L. G. WILLIAMS NASA - JOHNSON SPACE CENTER

APRIL 28, 1980

DESIGNING FOR THE SHUTTLE ERA GENERAL REQUIREMENTS DEFINITION

This chart summarized the Shuttle Programs approach to the definition of payloads accommodations and design requirements. It is important to note that ICD 2-19001 defines all of the payload interfaces. Most users require only a fraction of these accommodations and the standard allocation of these accommodations is defined in Volume XIV. ICD 2-19001 is used as the basis for payload specific ICD's. Each paragraph (or accommodation) is dispositioned as applicable, not applicable, exception or unique application. The intent is to always sign up the user to a set of interfaces equal to or less than the Shuttle accommodations. Thus avoiding unique modifications to the reusable Shuttle vehicle. The ICD 2-19001 is a contract requirement on the payload integration contract only. This is a unique approach as opposed to the expendable booster ICD's where a booster could be easily modified to the specific payload requirements.

DESIGNING FOR THE SHUTTLE ERA
GENERAL REQUIREMENTS DEFINITION

- SPACE SHUTTLE SYSTEM PAYLOAD ACCOMMODATIONS - DOCUMENT JSC 07700, VOLUME XIV
  - PROVIDES: CAPABILITIES OF SPACE SHUTTLE SYSTEM TO ACCOMMODATE PAYLOADS GENERAL DESCRIPTION OF SPACE TRANSPORTATION SYSTEM AND FLOW DESIGN CRITERIA FOR DEDICATED USERS AND MIXED USERS
  - CONTROL: MAINTAINED AND CONTROLLED BY SPACE SHUTTLE PROGRAM OFFICE
- SHUTTLE ORBITER/CARGO STANDARD INTERFACES - ICD 2-19001
  - PROVIDES: DEFINITION AND CONTROL OF SERVICES PROVIDED BY THE SHUTTLE SYSTEM AT THE USER INTERFACE.
    - DESIGN INTERFACES FOR:
      - MECHANICAL
      - STRUCTURAL
      - THERMAL
      - POWER
      - AVIONICS
      - SOFTWARE
    - DEFINES INDUCED ENVIRONMENTAL INTERFACES
    - DEFINES GENERAL INTERFACE CONSTRAINTS AND LIMITATIONS
  - CONTROL: MAINTAINED AND CONTROLLED BY SPACE SHUTTLE PROGRAM OFFICE

DESIGNING FOR THE SHUTTLE ERA GENERAL REQUIREMENTS DEFINITION

NHB 1700.7, Safety Policy and Requirements for Payloads using the STS represents a set of new requirements for payloads as opposed to those for expendable boosters. They are necessitated by the presence of the flight crew and their exposure to hazards for the attached phases of the mission. The responsibility for payload safety rest with the user and the NASA safety panel reviews the user provides analysis to assure understands the requirements. It does not perform detailed review and approval of the design and verification process but maintains an advisory and overview of the payload safety process.

JSC 14046, Payload Interface Verification Requirements is a new document defining the payload and STS interface verification requirements. It provides an overview of the STS interface verification process in preparation for integrated STS/Payload operations, defines payload interface verification requirements and defines integrated STS/Payload test objectives. Again the responsibility is placed on the user to define and execute his verification program.

DESIGNING FOR THE SHUTTLE ERA
GENERAL REQUIREMENTS DEFINITION

- SAFETY POLICY AND REQUIREMENTS FOR PAYLOADS USING THE STS - DOCUMENT NHB 1700.7
  - PROVIDES: POLICY AND MINIMUM SAFETY REQUIREMENTS APPLICABLE TO ALL STS PAYLOADS, AIRBORNE SUPPORT EQUIPMENT AND GROUND SUPPORT EQUIPMENT
  - CONTROL: MAINTAINED AND CONTROLLED BY NASA HEADQUARTERS
    JSC SAFETY PANEL ACTS ON WAIVERS BUT DOES NOT MODIFY REQUIREMENTS
- PAYLOAD INTERFACE VERIFICATION REQUIREMENTS - DOCUMENT JSC 14046
  - PROVIDES: BASIC REQUIREMENTS TO BE UTILIZED BY THE STS AND THE STS USER IN THE VERIFICATION OF PAYLOAD AND PAYLOAD GROUND AND AIRBORNE SUPPORT EQUIPMENT INTERFACES WITH THE STS.
  - CONTROL: MAINTAINED BY JSC SHUTTLE PAYLOAD INTEGRATION DEVELOPMENT OFFICE AND KSC CARGO PROJECTS OFFICE.
    CONTROLLED BY SHUTTLE PROGRAM OFFICE AS PART OF JSC 07700, VOLUME XIV

DESIGNING FOR THE SHUTTLE ERA CONCERNS

The NASA recognizes that designing for the Shuttle imposes new requirements and risk on the payloads. Hopefully this is offset by the additional capabilities and economy of using the system. The concurrent development of the STS and payloads creates a risk in designing to presently defined environments. My personal assessment is that conservation on the users

part at this point in time is desirable. For instance a contamination cover may be cost effective and provide mission assurance as compared to expensive analysis and low level of confidence at this point in time.

The length of time of attached operations for Shuttle payloads far exceeds that previously experienced on expendable launch vehicles. This imposes a new set of design requirements on the payload as well as providing additional capability for mission assurance checkout in orbit prior to committing to freeflight operations. We believe this is an area the user must recognize early in his development process, incorporate into his design requirements and utilize to his advantage.

The average user has not fully recognized the difference in the Shuttle program and expendable launch vehicles. Many are reluctant to accept standardization and design to the mixed user criteria. They fail to recognize that it is intended to maximize mission assurance as well as minimize costs. The best way to use a Shuttle is exactly as it was used successfully on the previous mission.

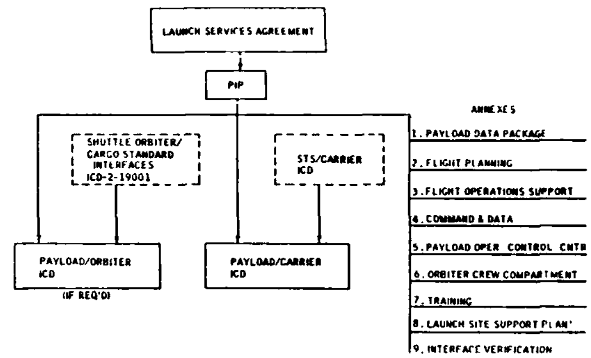
DESIGNING FOR THE SHUTTLE ERA
CONCERNS

- o CONCURRENT DEVELOPMENT OF PAYLOADS AND SPACE TRANSPORTATION SYSTEM
  - CREATES RISK IN DESIGNING TO PRESENTLY DEFINED INDUCED ENVIRONMENTS
    - LOADS
    - ACOUSTICS
    - THERMAL
    - CONTAMINATION
  - REQUIRES USE OF CONSERVATIVE DESIGN PRACTICES
- o SHUTTLE DESIGN AND OPERATIONS WILL NECESSITATE MORE ON-ORBIT TIME PRIOR TO DEPLOYMENT
  - RESULTS IN ADDITIONAL CONSTRAINTS WITH RESPECT TO THERMAL, POWER AND CONTAMINATION
- o SOME PAYLOADS DEMAND PREFERENTIAL TREATMENT WITH RESPECT TO LOCATION, PROVISION OF NON-STANDARD SERVICES AND FIRST DEPLOYMENT
  - REQUIRES EXTENSIVE NEGOTIATION
  - CONSTRAINING TO MANIFESTING OF CARGOES BY MISSION
  - RESULTS IN SIGNIFICANT CUMULATIVE PRODUCTIVE TIME LOSS FOR ALL INVOLVED
  - SPECIAL INTERFACES. DEVIATING FROM THE STANDARD. INCREASE PROBABILITY OF ANOMALY OCCURRENCE THEREBY POTENTIALLY AFFECTING MISSION SUCCESS

STS/PAYLOAD REQUIREMENTS DEFINITION DOCUMENTATION

This chart illustrates the relationship of the various requirements documentation in the STS payload integration process. We have previously discussed ICD 2-19001 and the payload specific ICD's of particular note is the Payload Integration Plan (PIP) which is used by JSC as a program level integration "statement of work", top level interface definition and integration activities schedule agreement. Major constraints on mission design and operation are defined, the launch sight operations are summarized, and all non-standard (optional) services are agreed in this document. It constrains the payload specific ICD development and PIP annexes which are user supplied data for mission implementation.

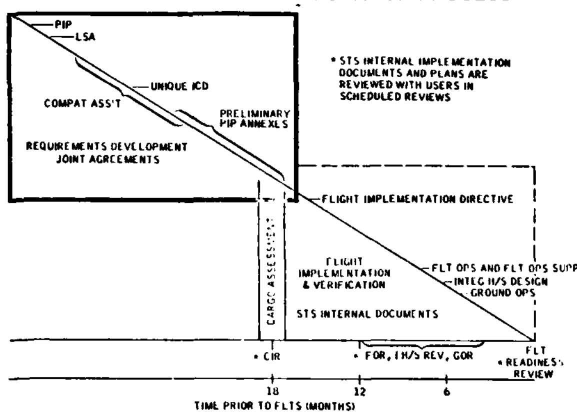
STS/PAYLOAD REQUIREMENTS DEFINITION DOCUMENTATION



SHUTTLE PAYLOAD INTEGRATION PROCESS

This chart illustrates the time frame for the overall payload integration process. Note that the requirements development is driven by the payload schedules. They should however be well defined by 2 years prior to flight in order to support an orderly integration process.

SHUTTLE PAYLOAD INTEGRATION PROCESS



Designing for the Shuttle Era-Structural Design for DOD Payloads

THE AEROSPACE CORPORATION

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Overview

- BASIC STRUCTURAL DESIGN REQUIREMENTS
- METHODS OF STRUCTURAL VERIFICATION
  - STRUCTURAL DESIGN/TEST CRITERIA OPTIONS
  - FRACTURE CONTROL
- SAFETY REVIEW PROCESS AND CERTIFICATION
- SHUTTLE STRUCTURAL LOADS ENVIRONMENT
  - LOW FREQUENCY REGIME (TRANSIENT RESPONSE)
  - HIGH FREQUENCY REGIME (ACOUSTICS)
- ENVIRONMENT VERIFICATION PROGRAM
  - GROUND TESTS
  - FLIGHT TEST DATA
- CONCLUDING REMARKS

Basic Structural Design Requirements

- NASA
  - SHUTTLE CREW AND ORBITER SAFETY
    - SUSTAIN ALL CRITICAL LOADS WITH A FACTOR OF SAFETY ≥ 1.4
    - LIFE VERIFICATION AND FRACTURE CONTROL
- AFSD
  - MISSION SUCCESS
    - SUSTAIN ALL CRITICAL LOADS WITH A FACTOR OF SAFETY ≥ 1.25
    - COMMANDER'S POLICY REQUIREMENTS
      - INDEPENDENT LOADS ANALYSES
      - TEST VERIFIED STRUCTURAL DYNAMIC MODELS
      - FRACTURE MECHANICS ANALYSES OF PRESSURIZED STRUCTURES
  - SHUTTLE CREW AND ORBITER SAFETY
    - SUSTAIN ALL CRITICAL LOADS WITH A FACTOR OF SAFETY ≥ 1.4
    - LIFE VERIFICATION AND FRACTURE CONTROL

Methods of Structural Verification

- OBJECTIVE: DEMONSTRATE COMPLIANCE WITH BASIC REQUIREMENTS
- PRIMARY STRUCTURE
  - STRENGTH - STRUCTURAL DESIGN/TEST CRITERIA OPTIONS
  - DEFORMATION - ANALYSIS, FOR CLEARANCE AND TRUNNION PULL-OUT
  - INTERFACE LOAD COMPATIBILITY - ANALYSIS, FOR COMPATIBILITY WITH ORBITER CAPABILITY
  - STRUCTURAL DYNAMIC CHARACTERISTICS - TEST VERIFICATION
  - LIFE VERIFICATION AND FRACTURE CONTROL - INSPECTION AND ANALYSIS (fracture control plan currently under review)
- SECONDARY STRUCTURE
  - COMPONENT VIBRATION QUALIFICATION TESTS
  - SYSTEM LEVEL ACOUSTIC TESTS

Structural Design / Test Criteria Options for DOD Payloads on Shuttle

- OPTIONS

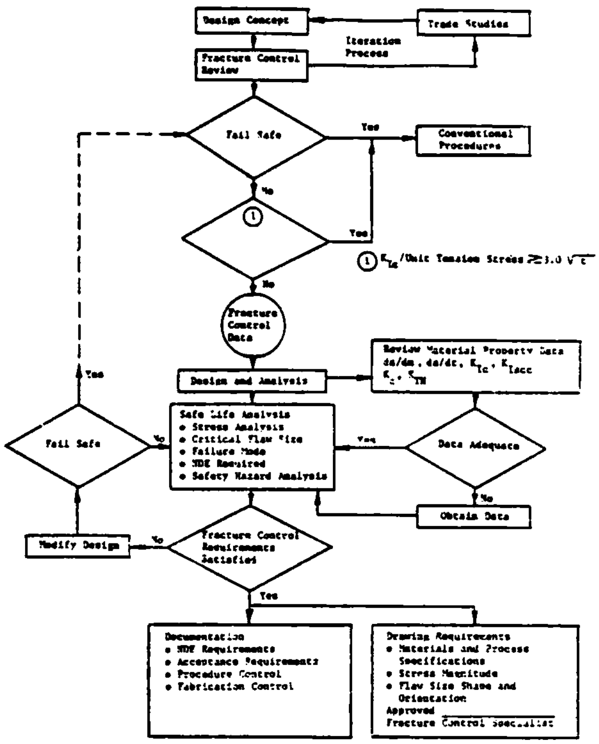
OPTION	TEST LEVEL*	FACTORS OF SAFETY YIELD	FACTORS OF SAFETY ULTIMATE	TEST SUCCESS CRITERIA	TYPICAL APPLICATION
1. TEST TO ULTIMATE (Baseline)	1.4	1.0	1.4	• NO FAILURES (1.4) • NO DETRIMENTAL DEFORMATION (1.0)	FLEET
2. REDUCED LEVEL TEST ON FLIGHT ARTICLE	1.25	1.25	1.4**	• NO DETRIMENTAL DEFORMATION	SMALL FLEET
3. PROOF TEST EACH FLIGHT ARTICLE	1.1	1.1	1.4	• NO DETRIMENTAL DEFORMATION	FEW
4. NO SYSTEM STATIC QUALIFICATION TEST	NA	1.6	2.25	NA	ONE-OF-A-KIND; MODS TO EXISTING S/C

*Factor multiplying limit load
**Note the additional analysis requirement below

ANALYSIS REQUIREMENTS
- POSITIVE MARGINS
- FOR OPTION 2, 15% MINIMUM MARGINS FOR STABILITY CRITICAL STRUCTURE

- APPLICABILITY: SAFETY-CRITICAL STRUCTURE ONLY, WITH REQUIREMENTS REDUCED TO MISSION SUCCESS LEVEL FOR NON-SAFETY-CRITICAL STRUCTURE
- STATUS
  - COMPATIBLE WITH CURRENT SPACECRAFT APPROACHES AND PAST AFSD PRACTICES
  - NASA/JSC POSITION
    - CONCURRENCE WITH ALL OPTIONS
    - DEVIATION/CONCURRENCE REQUIRED IN CLASSIFYING STRUCTURE AS "NON-SAFETY-CRITICAL"

Fracture Control Approach (under review)



Safety Review Process and Certification

- DOD STS SAFETY REVIEW TEAM (SRT) CONDUCTS FOUR DETAILED TECHNICAL REVIEWS
  - FUNCTION IS TO ENSURE THAT DOD STS SAFETY REQUIREMENTS ARE INCORPORATED INTO PAYLOAD DESIGN
  - TYPICAL SRT MEMBERSHIP: YVAS ACCIDENT PREVENTION MANAGER OR PAYLOAD ENGINEERING OFFICER, AEROSPACE, SAMTO, NASA-KSC, NASA-JSC/SPIDPO, PIC, BOEING (IUS PAYLOADS ONLY), SD/SE (ADVISOR)
- SRT PRESENTS RECOMMENDATIONS ON FINAL SAFETY CERTIFICATION TO DOD STS SAFETY CERTIFICATION PANEL (SCP)
  - SCP MEMBERSHIP: SAMTO, SD/SE, NASA (HDQTRS), AEROSPACE
- SCP MAKES RECOMMENDATION FOR CERTIFICATION TO DOD STS SPD
- DOD STS SPD AND PAYLOAD SPD SIGN CERTIFICATE OF SAFETY COMPLIANCE (CSC)
- CSC PRESENTED TO NASA (SPIDPO) IN ACCORDANCE WITH THE DOD/NASA PAYLOAD CERTIFICATION AGREEMENT

Shuttle Structural Loads Environment

- LOW FREQUENCY REGIME LOADS - DERIVED FROM COUPLED SHUTTLE/PAYLOAD DYNAMIC AND QUASISTATIC ANALYSES (load cycles)
  - INGREDIENTS
    - SHUTTLE DYNAMIC MODELS AND FORCING FUNCTIONS GFP FROM NASA
    - SPACECRAFT DYNAMIC MODELS AND LOAD TRANSFORMATION MATRICES FROM SPACECRAFT CONTRACTORS
    - TRANSFER STAGE (e.g., IUS, PAM-D) DYNAMIC MODELS, FORCING FUNCTIONS AND LTM's FROM CONTRACTOR
  - ANALYSIS METHODOLOGY FOR EACH SPACECRAFT SYSTEM
    - LIFTOFF AND LANDING LOADS BY DYNAMIC ANALYSIS
    - QUASISTATIC LOADS ANALYSES FOR OTHER EVENTS (gust, engine shutdowns, stagings, etc.), INCLUDING THERMAL EFFECTS

Shuttle Structural Loads Environment (Cont'd)

- HIGH FREQUENCY REGIME LOADS- ENGINE ACOUSTIC NOISE
  - NASA ICD 2-19001 SPEC LEVEL BASED ON TITAN SPECS
  - CARGO BAY ACOUSTIC PREDICTION MADE ON BASIS OF LIMITED GROUND TESTS
    - 6.4% MODEL DATA USED FOR BASIC ENVIRONMENT DEFINITION
    - FULL SCALE NOISE REDUCTION TESTS ON ORBITER
    - QUARTER-SCALE MODEL TESTS
    - MODEL-TO-FULL SCALE COMPARISON DATA
  - RESULTS
    - PAYLOAD PRESENCE AFFECTS CARGO BAY LEVELS
    - CONTROVERSY OVER LOW FREQUENCY LEVELS WHOSE RESOLUTION REQUIRES FLIGHT DATA

- THREE LOAD CYCLES
  - PRELIMINARY - SUPPORTS SPACECRAFT PRELIMINARY DESIGN REVIEW (PDR)
  - FINAL DESIGN - SUPPORTS SPACECRAFT CRITICAL DESIGN REVIEW (CDR) AND NASA CARGO INTEGRATION REVIEW (CIR)
  - VERIFICATION - FINAL PREFLIGHT VERIFICATION OF STRUCTURAL ADEQUACY
- UNCERTAINTY FACTORS APPLIED
  - MATURITY OF BOOSTER MODELS AND FORCING FUNCTIONS
  - MATURITY OF SPACECRAFT SYSTEM MODELS
  - CURRENT VALUES FOR TYPICAL SPACECRAFT PROGRAM

	PRELIMINARY	FINAL DESIGN	VERIFICATION
SPACECRAFT	1.5	1.25	1.0
IUS	1.5	(1.5)	(1.5)
SHUTTLE	1.5	(1.5)	(1.5)

- INDEPENDENT CONTRACTOR EFFORT
  - VERIFICATION CYCLE LOADS ANALYSIS
  - CONCURRENCE WITH TEST VERIFICATION OF DYNAMIC MODEL

Maximum Predicted SPL with A Small (60% diameter) Payload

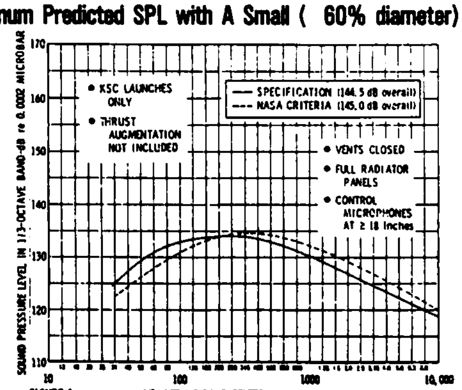


FIGURE 1

Maximum Predicted SPL with a 14 ft Diameter Payload

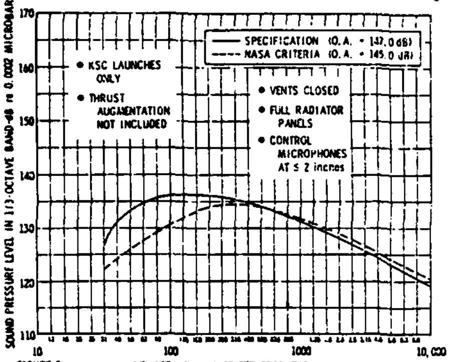


FIGURE 2

Environment Verification Program

- *EXTENSIVE GROUND TEST PROGRAMS*
  - SHUTTLE DYNAMIC MODEL VERIFICATION PROGRAM
    - QUARTER-SCALE MODEL MODAL TESTING
    - HORIZONTAL GROUND VIBRATION TEST (HGVT) AND MATED VERTICAL GROUND VIBRATION TEST (MVGVT)
    - QUARTER-SCALE PAYLOAD MODEL MODAL TESTING WITH SIMULATED CARGO ELEMENT MODELS
    - STATIC INFLUENCE COEFFICIENT TESTS
  - IUS DYNAMIC MODEL VERIFICATION PROGRAM
    - DEVELOPMENT MODEL MODAL TESTING
    - FLIGHT CONFIGURATION MODAL SURVEY
  - SPACECRAFT DYNAMIC MODEL VERIFICATION
    - MODAL SURVEY OR REDUCED LEVEL TESTING FOR DYNAMICALLY SIMPLE SYSTEMS
  - SHUTTLE FORCING FUNCTIONS
    - SRM AND SSME GROUND FIRINGS
    - SCALE MODEL TESTING FOR DEFINITION OF OVERPRESSURE FORCING FUNCTION

- MEASUREMENT PROGRAM FOR FLIGHT
  - OBJECTIVES
    - VERIFICATION OF (low frequency) STRUCTURAL LOADS PREDICTION METHODOLOGY
    - VERIFICATION OF ACOUSTIC ENVIRONMENT
    - DIAGNOSTICS
  - CURRENT LEVEL OF EFFORT
    - BASIC SHUTTLE MEASUREMENT PROGRAM
    - MADS (MODULAR AUXILIARY DATA SYSTEM)
  - CONCERNS
    - LIMITED MEASUREMENTS
    - INAPPROPRIATE FREQUENCY RANGES (2-50 Hz vs 0-50 Hz)
    - NO CLEAR PROGRAM OF DATA ANALYSIS AND EVALUATION DEFINED
    - NO ON-GOING MINIMUM LEVEL PROGRAM DEFINED FOR DIAGNOSTIC PURPOSES

Concluding Comments

- BASIC APPROACH OF AN INTEGRATED PROGRAM OF DESIGN, ANALYSIS, AND TEST USING THE SAME CONCEPTS AS EMPLOYED ON EXPENDABLE BOOSTERS-- LOAD CYCLES, UNCERTAINTY FACTORS, MODAL SURVEYS, STATIC TESTS, AND ACOUSTIC TESTS-- IS GENERALLY APPLICABLE TO DESIGN OF DOD SYSTEMS IN THE SHUTTLE ERA AS THE MEANS OF ASSURING MISSION SUCCESS
  - NASA HAS SUPPORTED EXTENSIVE GROUND TEST PROGRAMS IN AN EFFORT TO ASSURE ADEQUATE DEFINITION OF THE ENVIRONMENT PRIOR TO ACTUAL FLIGHT TEST
  - SPECIFIC STRUCTURAL DESIGN/TEST CRITERIA OPTIONS HAVE BEEN DEFINED FOR DOD SPACECRAFT TO ALLOW FLEXIBILITY IN SPACECRAFT DESIGN AND TO FACILITATE PROGRAM PLANNING
- MAJOR PROBLEM AREA HAS BEEN A RESULT OF SPACECRAFT AND BOOSTER PARALLEL DEVELOPMENT
  - ACCENTUATES VARIABILITY IN THE DEFINITION OF THE LOW FREQUENCY DYNAMIC LOADS ENVIRONMENT
  - PRECLUDES ADEQUATE DEFINITION OF ACOUSTIC ENVIRONMENT
  - ASSESSMENTS HAMPERED BY LACK OF ADEQUATE VISIBILITY INTO SUCH AREAS OF POTENTIAL VARIABILITY AS SHUTTLE LOADS METHODOLOGY AND FORCING FUNCTIONS

Concluding Comments (Cont'd)

- SOME SHUTTLE-UNIQUE TECHNICAL PROBLEMS HAVE ALSO BEEN INTRODUCED
  - APPARENT NEED FOR EXPANDED FRACTURE CONTROL REQUIREMENTS (CURRENTLY UNDER REVIEW AND ASSESSMENT OF IMPACT)
  - CARGO BAY ACOUSTIC ENVIRONMENT LEVELS IN LOW FREQUENCY REGIME ARE APPARENTLY SENSITIVE TO CARGO PRESENCE, WITH THE POTENTIAL FOR INTERACTING WITH THE LOW FREQUENCY STRUCTURAL DYNAMICS
  - FRICTION EFFECTS AT CARGO ELEMENT/ORBITER INTERFACES ARE IMPACTING ANALYSIS METHODOLGY AND GROUND TESTING
- *SOME SYSTEM PROBLEMS TYPICAL OF EXPENDABLE BOOSTERS AND AFFECTING STRUCTURAL DESIGN PERSIST*
  - SHUTTLE/CARGO ELEMENT FLIGHT CONTROL SYSTEM/STRUCTURAL DYNAMIC INTERACTION PROBLEM (IUS LOW RESPONSE SYSTEM)
  - DIFFICULTY IN OBTAINING ADEQUATE PROGRAM OF MEASURED DATA TO VERIFY THE ENVIRONMENTS AND LOADS PREDICTION METHODOLOGY

Designing for the Shuttle Era

STS Integration Perspective

Given at: Mission Assurance Design Workshop
Workshop B
H.E. Emigh
April 1980

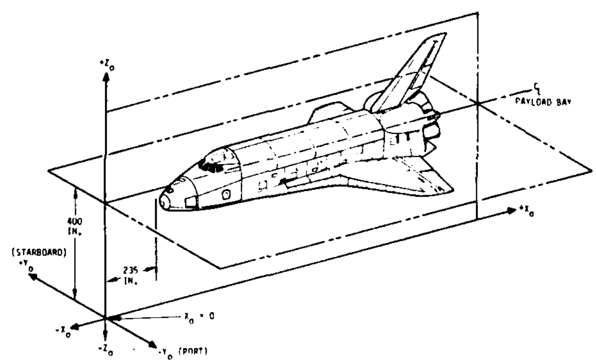
REUSABILITY

With the beginning of the Shuttle era, some new issues are being faced in space technology which are old hat to our aircraft counterparts. The capabilities of Shuttle now offer an opportunity for the return and subsequent reuse of payloads for multi-missions. In addition, for Shuttle delivery missions, improving upper stages such as the inertial upper stage and payload aft module, new equipment, called airborne support equipment (ASE), is returned with the Shuttle for subsequent reuse. Equipment in this category involves control systems for the aft flight deck (AFD) of the Shuttle, as well as structural support cradles and interfacing electronics which remain in the payload bay after the upper stage has been deployed. The reuse of the equipment introduces a new dimension to space technology in fatigue lift - both acoustic fatigue and aircraft-type fatigue considerations with respect to fracture mechanics. The Shuttle and Spacelab programs have instituted fatigue life analysis and testing for these disciplines which are similar to what is deployed in the aviation industry today. It has not appears as though MIL STD 1540, the testing standard for spacecraft systems, has not as yet been revised to encompass these new dimensions, and certainly these considerations are fundamentally a part of mission assurance in the Shuttle era.

REUSABILITY

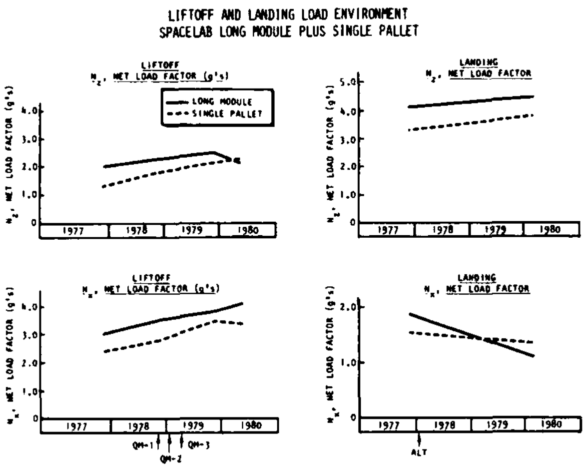
- SHUTTLE CAPABILITY TO RETURN PAYLOADS INTRODUCES NEW ISSUES TO SPACE TECHNOLOGY
- SHUTTLE SORTIE MODE & RETURNED AIRBORNE SUPPORT EQUIPMENT (ASE) DICTATE NEW CONSIDERATIONS FOR FATIGUE LIFE
    - ACOUSTICS
    - FRACTURE MECHANICS
- SHUTTLE & SPACELAB HAVE IMPLEMENTED AIRCRAFT-TYPE OF TESTING/ANALYSIS APPROACHES
- MIL STANDARD 1540 SHOULD REFLECT THIS CHANGE IN SPACE UTILIZATION

ORBITER COORDINATE SYSTEM



LIFTOFF AND LANDING LOAD ENVIRONMENT

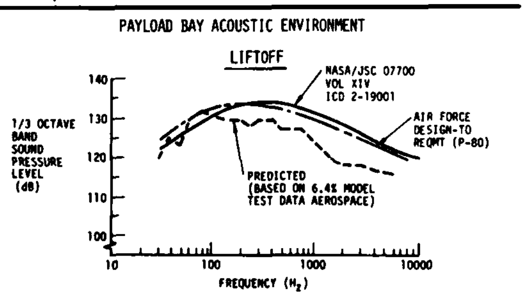
The Spacelab long module plus single pallet is typical of how Shuttle payloads have evolved. Important parameters affecting the liftoff loads are the updates to the forcing functions that resulted from the SRB DM (development motor), the QM (qualification motor) test firing data, vehicle modle updates, and the main engine propulsion test (MPT). Important parameters affecting the landing forcing functions are the main landing gear forces that were updated after the approach nd landing test (ALT). The maximum loads are two sigma values with a probability of 0.98.



A.2 PAYLOAD BAY ACOUSTIC ENVIRONMENT

The acoustic environment in the empty orbiter cargo bay is produced by rocket engine exhaust noise during liftoff and by boundary-layer pressure fluctuations (aeronoise) during the Mach 1, maximum-dynamic-pressure portion of ascent aerodynamic flight.

The NASA acoustic environment for an empty cargo bay, as specified in NASA/JSC 07700, Volume XIV, is shown along with the predicted environment based upon 6.4 percent model tests. It es expected, based upon previous program experience, that the predicted values will shift one octave to the right, and thus, closely match the specified Volume XIV data. Acoustic level measurements collected during the OFT program (STS flights 1 through 4) will resolve the scaling question. Also shown in the drawing is the Air Force design-to-acoustic environment which conservatively encompasses the predicted environment.



ISSUE: WORST CASE PREDICTIONS INDICATE A SLIGHT EXCEEDING OF SPECIFICATIONS IN LOWER FREQUENCY RANGE

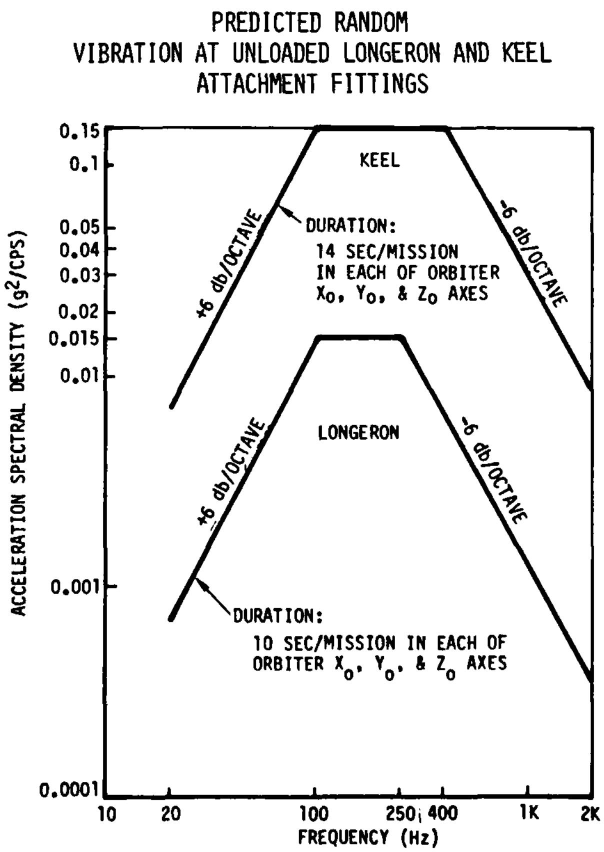
- ON PREVIOUS PROGRAMS, MODEL EXTERNAL NOISE DATA PEAKS AT FREQUENCIES OVER ONE OCTAVE LOWER THAN FULL SCALE DATA
- OFT PROGRAM (STS FLIGHTS 1 THROUGH 4) WILL RESOLVE SCALING QUESTION

A.3 PREDICTED RANDOM VIBRATION AT UNLOADED LONGERON AND KEEL ATTACH FITTINGS

The Space Shuttle vehicle will be subjected to fluctuating pressure loading on its exterior surfaces caused by engine exhaust-generated acoustic noise during liftoff and aerodynamic noise during atmospheric flight. These fluctuating pressure loads are the principal sources of structural vibration.

The predicted maximum random vibration at the unloaded (i.e. empty cargo bay) longeron and keel cargo attach fittings, caused by these fluctuating pressure loads, is shown in the accompanying drawing. Actual vibration input to cargo elements will depend upon the cargo element weight, center of gravity location, and stiffness of each cargo element and the cargo element support and retention structure.

There is an estimated 95 percent assurance, based upon solid and liquid engine test data and detailed analysis, that the predicated levels are accurate. Final verification will be obtained during the OFT program.



PREDICTED THERMAL ENVIRONMENT

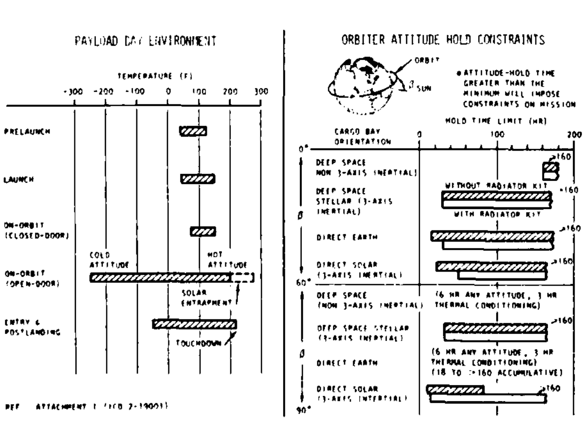
The current predicted thermal environment in the cargo bay is expected to remain the same and will be updated or modified as required on the basis of flight data obtained during the initial orbiter flights.

Current predictions of the thermal environment for various mission phases are derived from analytical results utilizing sophisticated computer programs and thermal math models of the orbiter and payloads. A typical cargo bay wall temperature range, as given in NASA ICD 2-19001, "Shuttle Orbiter/Cargo Standard Interfaces," is illustrated for the various mission phases.

Predictions for specific payloads are dependent upon flight parameters and cargo element configurations, and thus, require integrated cargo/orbiter analysis. This is particularly important if solar entrapment could occur during on-orbit operation when the cargo bay doors are open. Solar entrapment may occur when solar radiant energy is trapped within a cavity such as a narrow gap or space between a payload surface and the cargo bay liner. If solar entrapment does occur, the resultant temperature within the cavity could reach high values and may exceed temperature limits of both the payload and the orbiter. Currently, NASA and Rockwell are studying solar entrapment to aid in predicting and in preventing or mitigating its effects.

To establish the on-orbit thermal environment, an important consideration is the orbiter attitude hold constraints which are dependent upon the orbiter attitude and angle, as illustrated. There is a ±30°F uncertainty on range boundaries.

PREDICTED THERMAL ENVIRONMENTS STATUS



PREDICTED CONTAMINATION LEVELS ALONG LOS 1 DUE TO ORBITER SOURCES

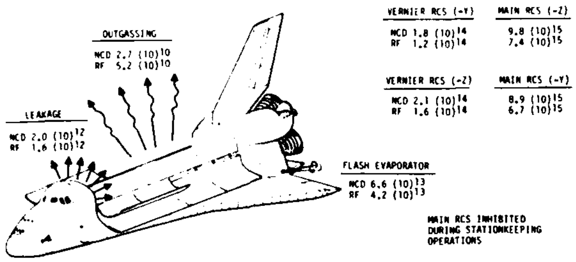
The major contamination sources attributable to the orbiter during on-orbit operations are shown in the accompanying drawing. The values have been established by using the NASA-funded Shuttle/Payload Contamination Environment (SPACE) computer program. The drawing indicates the levels caused by various effluents which a sensor would see along LOS 1. The number column densities (NCD) give the number of molecules per square centimeter in the optical path. This is a measure of the attenuation which can be expected by the various contaminant molecular species due to absorption and scattering of the signal photons. The return flux (RF) is a measure of the time rate of incidence of the molecular species upon a sensor located at the LOS 1 origin.

During on-orbit data accumulation operations, the main RCS jets are inhibited and only the vernier jets are used for station keeping. Two vernier jets are located in the nose, one on either side, and fire downward; four verniers are located in the aft end, two on either side as shown in the drawing. None of the verniers fires toward the region above the payload bay.

Flash evaporator ports are located on either side of the aft end of the orbiter (see drawing) and vent in the plus and minus y directions simultaneously. The evaporators boil excess potable water, generated by the fuel cells, to maintain the subsystems within tolerable temperature ranges. The quantity of water expelled is a function of several variables, of which β-angle and power consumption are dominant. Under certain favorable conditions the flash evaporator system can be inhibited, thereby removing a significant contribution to the on-orbit contamination environment.

Environment predications similar to those shown on the drawing have been made for several other LOS. These are documented in the Stand Interface ICD 2-19001.

PREDICTED CONTAMINATION LEVELS ALONG LOS 1
DUE TO ORBITER SOURCES



LOS 1 - ZERO DEGREE LINE OF SIGHT (IN THE $+Z_0$ DIRECTION) ORIGINATING AT $X_0 = 1107$, $Y_0 = 0$, $Z_0 = 507$

NCD - NUMBER COLUMN DENSITY (MOLECULES/CM^2)

RF - RETURN FLUX AT 300 KM (MOLECULES/CM^2/SEC)

ENVIRONMENT MEASUREMENT PROGRAMS

The ALT, SRB, quarter scale, and MPTA test programs all are limited in that they do not reflect the flight configuration and launch facilities of the Shuttle. The interaction of the various Shuttle elements (MPS, SRB, ET, launch facilities, and payloads) is expected to have a significant effect on the various induced environments under consideration. The OFT program will be the first chance to obtain data from all inputs simultaneously. While the past and current programs provided some confidence that the predicted environmental data are valid, only the OFT flights will verify the predictions or provide data to update them.

In-flight verification of payload responses will be provided by 38 wideband instruments on STS-2, -3, and -4. Acceleration load factors will be measured by 16 low-frequency accelerometers, vibration responses by 8 high-frequency accelerometers, and acoustics by 14 microphones.

Temperature sensors on STS-3 will measure payload retention fitting temperatures during all mission phases. Frictional loads at the fittings will be determined from the temperature data.

The induced environment control monitor (IECM) will measure Shuttle- and payload-induced contamination of STS-1 through STS-4.

ENVIRONMENT MEASUREMENT PROGRAMS

ACOUSTIC
- MPTA TESTS
- SRB DEVELOPMENT & QUAL TESTS*
- QUARTER-SCALE GVT (INFLUENCE OF PAYLOADS IN BAY 3 CONFIGURATION)*
- OFT PROGRAM
- MADS - STS-2**

LOADS
- MPTA TESTS (LIFTOFF FORCING FUNCTIONS)
- APPROACH & LANDING TEST (LANDING FORCING FUNCTIONS)*
- GROUND STRUCTURAL TESTS (SHUTTLE MODELS)*
- QUARTER-SCALE GVT (PAYLOAD-SHUTTLE RESPONSE)*
- OFT PROGRAM
- MADS - STS-2**

CONTAMINATION
- IECM (OFT)

THERMAL
- OFT PROGRAM

VIBRATION
- MPTA TESTS
- QUARTER-SCALE GVT*
- OFT PROGRAM
- SRB*

*COMPLETE
**MODULAR AUXILIARY DATA SYSTEM (MADS)
- STS-2 & SUBSEQUENT FLIGHTS (TO BE DEFINED)

UPDATE FORECAST FOR ENVIRONMENTS

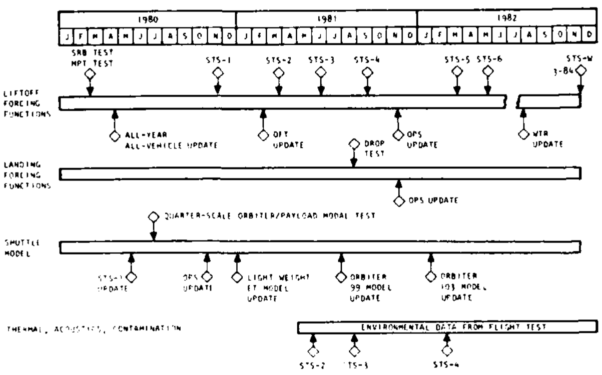
The Shuttle environments will be periodically updated prior to Shuttle operational flights.

Development and qualification motor tests of the SRB's have been completed. The results, along with MPT test results, have been incorporated into the all-year, all-vehicle liftoff forcing functions. Future liftoff forcing function updates utilizing flight data are anticipated during the OFT program.

Landing forcing functions, with a 9.6-foot per second sink rate, are causing structural load problems for the orbiter. To alleviate gear loads, the main gear (metering pin) may be modified prior to operational flight. This will necessitate a qualification test program and landing gear forcing function update.

The Shuttle math models will be updated to the GVT and STA test results for the OFT program, and for the operational flights of Orbiter 102. Additional model updates will be made for the lightweight ET and for Orbiters 099 and 102.

UPDATE FORECAST FOR ENVIRONMENTS



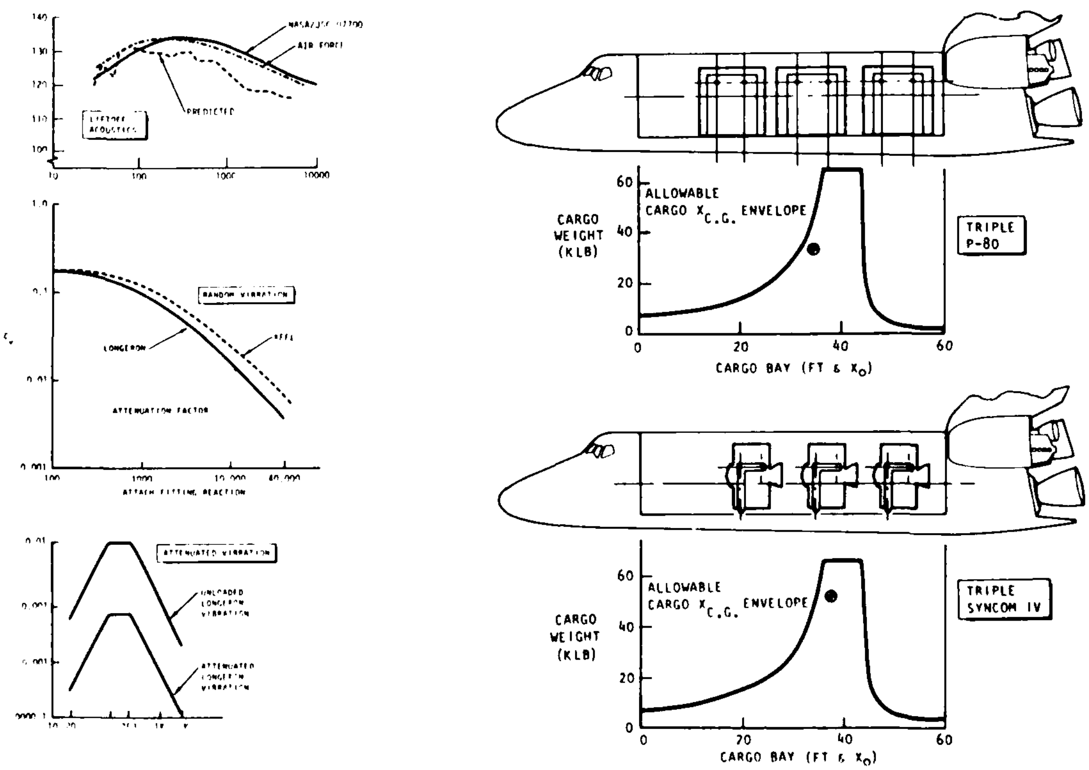
MULTIPLE CARGO ANALYSIS STRATEGY STRUCTURAL LOADS

Preliminary cargo element design is partly guided by the limit load factors presented in JSC 0700, Volume XIV, for liftoff and landing. However, dynamic response of the cargo element is dependent upon and can be magnified by its location in the cargo bay and the presence of companion cargo elements. Therefore, when uncertainty exists as to the planned location of a particular cargo element and/or the mix of companion cargo elements, the dynamic loads analysis must be conducted in a manner which will ensure the design adequacy of that cargo element regardless of its location or the presense of other cargo elements.

As illustrated, this goal can be achieved by performing the coupled orbiter/cargo element dynamic loads analysis with some multiple of the cargo element, as constrained by cargo element size, weight, and the allowable cargo $X_{c.g.}$ envelope installed in the cargo bay. When mixed with other cargo elements, the analysis results will define the dynamic loads at each of the potential cargo element locations and identify the maximum expected dynamic loads.

Although the cargo bay acoustic environment may be attenuated by the presence of other cargo elements, design of a particular cargo element should anticipate exposure to the limit acoustic environment previously shown. Similarly, the presence of other cargo elements in the cargo bay will attenuate, dependent upon their weights, the random vibration input at the longeron and keel attach fittings. However, design of a particular cargo element should consider only that attenuation resulting from its own weight, as illustrated.

MULTIPLE CARGO ANALYSIS STRATEGY STRUCTURAL LOADS



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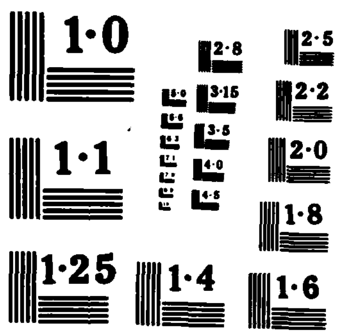

1·0
2·8
2·5
3·15
2·2
3·5
1·1
4·0
2·0
4·5
1·8
1·25
1·4
1·6

MULTIPLE PAYLOAD CARGO ANALYSIS STRATEGY THERMAL INTEGRATION

For each cargo element, three analysis cycles will be performed, starting with the payload design analysis and followed by the compatibility analysis and then the verification analysis, as illustrated. As progress is made from one analysis cycle to the next, better and detailed definition of the various cargo elements, their location and position in the cargo bay, and the mission parameters are established and used in the analysis.

For each payload or cargo element, the design analysis can be performed by utilizing a simple cargo bay thermal math model with only the payload model in an assumed location. This results in the worst design condition. Generally, entry and on-orbit mission phases result in a maximum or minimum thermal environment.

For payloads which may be sensitive to thermal interactions with other cargo elements, simple representative thermal models of those cargo elements could be included.

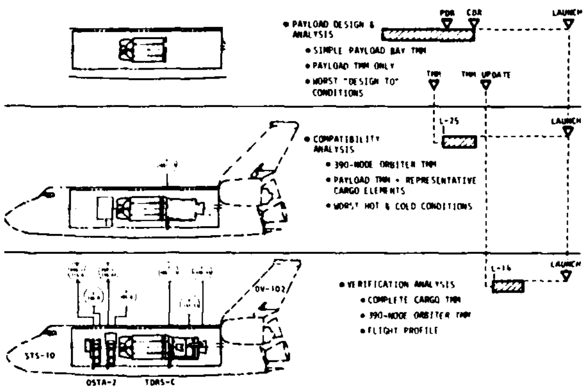
To perform the compatibility analysis, the 390-node orbiter thermal math model developed by NASA will be used. If all the cargo TMM's are not available, representative TMM's would be used unless there is indication that this would compromise the analysis results. The objective of this analysis is to determine if there are any thermal problems or issues associated with a payload flying with the orbiter for various mission phases.

The last analysis, the verification analysis, will be performed 14 months prior to launch. For this analysis, a complete cargo TMM will be used with each cargo element location defined. The objective of TMM's analysis is to verify thermal compatibility for the planned operational conditions and flight profile.

Under contract from NASA, Rockwell will perform the compatibility and verification analyses. These analyses will be performed as part of the standard services. This requires each payload contractor to provide thermal math models in accordance with the published NASA criteria/guidelines for math models.

In addition, optional services are available to the payload contractor to augment the standard analysis cases, connections, and thermal models. Optional services range from the development or modification of payload thermal math models to a wide range of integrated analyses.

MULTIPLE PAYLOAD CARGO ANALYSIS STRATEGY
THERMAL INTEGRATION

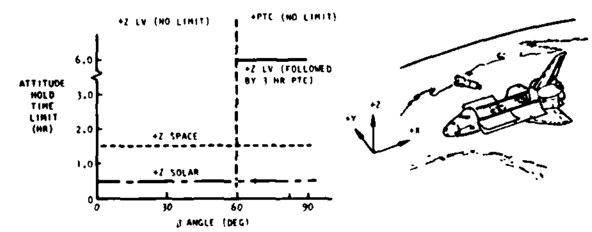


MULTIPLE PAYLOAD CARGO ANALYSIS STRATEGY THERMAL ATTITUDES

For multiple payload cargos, particularly those that include deployable-type payloads, NASA has established payload attitude hold requirements. Essentially, the payload is required to withstand direct solar exposure, (the cargo bay facing the sun) for at least 30 minutes, and to withstand a cold condition (with the cargo bay pointed towards deep space) for 90 minutes. To meet the attitude hold requirements, payloads are being designed with a removable thermal shroud.

MULTIPLE PAYLOAD CARGO ANALYSIS STRATEGY

• PAYLOAD ATTITUDE HOLD REQUIREMENTS



• CONTAMINATION
- • NASA-DEVELOPED CONTAMINATION COMPUTER PROGRAM (SPACE) WILL BE USED TO ANALYZE MULTIPLE PAYLOADS

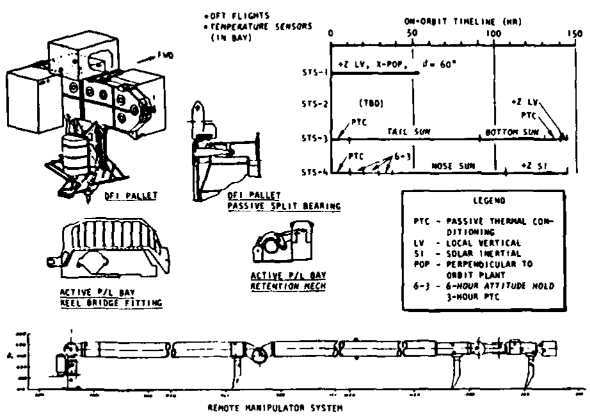
MEASUREMENT PROGRAMS FOR THERMAL ENVIRONMENTS

To provide thermal data and to monitor temperatures in specific areas, 17 permanent temperature sensors are located in the cargo bay. In addition, for the initial orbiter flights, 16 additional sensors will be located in the cargo bay.

These sensors plus those that are located throughout the orbiter structure will be used to update and modify the predicted temperatures and the orbiter thermal math models.

For the initial orbiter flights, the flight attitudes and timelines have been carefully selected to provide thermal data that will establish the temperature ranges and the attitude constraints.

MEASUREMENT PROGRAMS FOR THERMAL ENVIRONMENTS



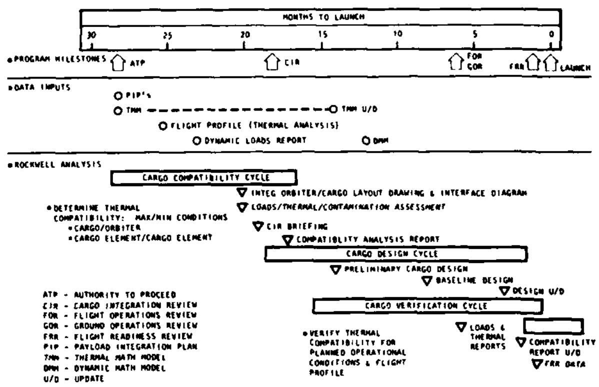
MULTIPLE CARGO ANALYSIS STRATEGY

A cargo compatibility assessment analysis will be performed regarding loads, thermal conditions, and contamination based upon data provided by the individual cargo contractors. Individual and cumulative cargo element loads imposed upon the orbiter will be assessed as will thermal conditions and contamination interactions. Acoustic levels will be effected by the volume and absorption of the combined cargo configuration. Attenuation of random vibration will be dependent upon the weight of the various cargo elements. A preliminary layout drawing and interface diagram will be produced reflecting cargo element installation requirements, mass properties, electrical and fluid services, cargo element envelope, trummion locations, and electrical and fluid interfaces with all orbiter-provided serivces. The effort will culminate in a cargo integration review and a compatibility assessment report.

During the cargo design cycle, a preliminary cargo design will be developed which will mature into a baseline design and a design detailing all cargo elements, flight kits, required hardware lists, and assembly and disassembly technical orders.

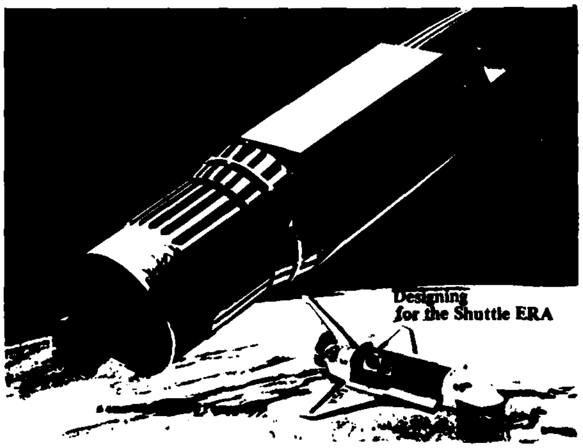
During the cargo verification cycle, independent loads and thermal analyses will be performed by Rockwell to assure orbiter-cargo configuration compatibility. The compatibility assessment report will be updated accordingly and FRR certification sheets and data packages will be prepared.

MULTIPLE CARGO ANALYSIS STRATEGY



"THE IUS PERSPECTIVE"

John Eckle
IUS Chief Engineer
Boeing Aerospace Corporation



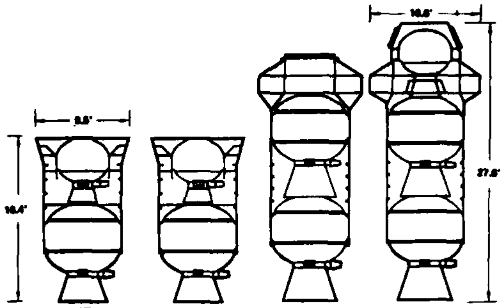
IUS VEHICLE FAMILY

The IUS system is composed of a family of vehicles tailored for alternative payloads and missions and capable of being boosted to low earth orbit by either the space shuttle orbiter or the Titan T34D launch vehicle. Common building blocks (modules) are designed to be used in each of the vehicle configurations.

Four solid rocket motor (SRM) combinations, using only two different sized motors, provide a family of IUS vehicles which satisfies the wide range of performance and interfacing requirements for all DOD and NASA missions. The large motor (21,400 pounds of propellant) is used in the first stage of all vehicle configurations. It is also used as the second stage of the NASA twin-stage vehicle. The small motor (6000 pounds of propellant) is the second stage of the two-stage configuration and the third stage of the three-stage spinner.

The IUS vehicle functions include stage structure, solid rocket motors, reaction control, thermal control and avionics. The avionics functions include guidance, navigation and control; telemetry, tracking and command communications; instrumentation; data management; electrical power and distribution; and on board computation. There is a high level of commonality in the avionics elements used in each of these vehicle configurations.

IUS Vehicle Family



Configuration	Titan Two Stage	Shuttle Two Stage	NASA Twin Stage	Twin Plus Spin
Payload Requirement	4,977 LB To GSO	5,000 LB To GSO	11,464 LB To Venus	4,842 LB To Jupiter
Initial Flight Capability	Mid 1981	Mid 1981	1985	Int. Solar Polar 1985 Galileo - Feb '84

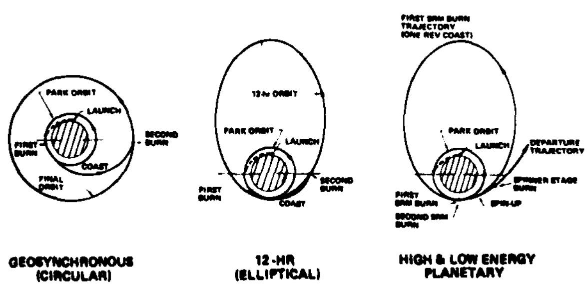
- Fully Redundant Systems—Predicted Reliability—0.976
- On-Board Active Guidance

IUS DESIGN REFERENCE MISSIONS

The IUS system is designed to accomodate a wide range of mission types. The two stage versions (T34D and STS compatible) are designed primarily for the geosynchronous (circular orbit) but could be made to accomodate a 12 hour (elliptical) orbit with a substantial performance surplus.

Planetary missions can be accomodated by the twin-stage configuration (2 large solid rocket motors (SRM's) - 2-stage vehicle) for low energy missions or the twin-plus-spin configuration (3-stage vehicle with 2 large SRM's and a small spin stabilize 3rd stage SRM).

IUS Design Reference Missions



IUS DESIGN PHILOSOPHY/CONSTRAINTS

Several key design philosophies and program constraints have provided the fundamental framework for the IUS design and testing approach. The application of these philosophies into the design at an early time period are ultimately responsible for

the flexibility of the design to reliably accomodate the specific missions to be flown and to achieve low life cycle costs.

The most fundamental design philosophy was in the decision to design generic vehicle configurations as opposed to specific vehicles to match each payload. This required that the characteristics of all known payloads and mission types be identified and pulled together into a set of generic spacecraft specifications and generic mission specifications so that a generic IUS configuration could be designed. Specific spacecraft known to require unique upper stage features are accomodated by providing "production options" in the design which can be ordered at the time the spacecraft is designated for IUS. The generic IUS design approach has resulted in being able to maximize commonality of modules (particularly SRM's and Avionics) between IUS vehicle configurations.

High reliability requirements obviously maximizes mission success probability. This requirement has been a fundamental tool in the selection of the optimum redundancy for elements of the system. High reliability parts (SAMSO-STD-73-2C) take advantage of past failure histories to minimize recurrence of past part problems through added controls, and application controls.

Qualification and acceptance testing is governed by MIL-STD-1540A which imposes margins on environmental test levels to provide conservatism to offset possible error in the analytical process of deriving the anticipated flight environment.

The parallel design/development cycle for two new vehicles (orbiter and IUS) has introduced the risk of an iterative design process as the design process for each vehicle evolves. The particular areas of concern are: changing dynamic forcing functions, changing interface definitions, and the lack of real flight environmental data.

IUS Design Philosophy

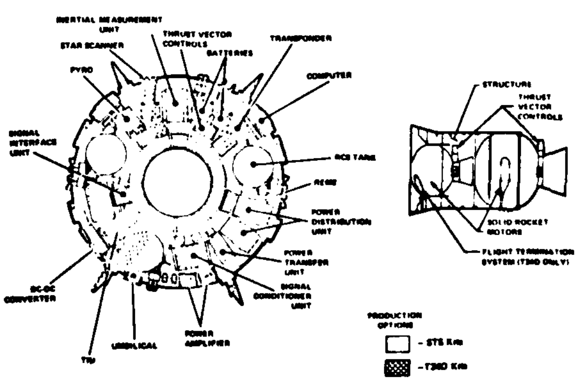
- **Generic design with production options**
- **Mission specifications for family of mission types**
- **Maximize commonality of STS/T34D/planetary applications - joint development**
- **Accommodate transitioning and new spacecraft types**
- **High reliability: 0.96 requirement, 0.98 goal**
- **Hi-qual E/E parts per SAMSO–STD–73–2C**
- **Test to MIL-STD-1540A**
- **Design/development in parallel with shuttle**

IUS SUBSYSTEM ELEMENTS

The generic two stage vehicle configuration for T34D and STS applications possesses a high degree of commonality. Differences are principally those required to accommodate two radically different launch vehicles: structural interface differences, electrical/electronic interface differences, and the need to provide a flight termination (destruct) system on the T34D.

Production options are provided in the generic design so that specific users may select features which may be desirable for their unique mission. Principal production options include: a third hydrazine tank, a second Tracking Telemetry and Control string, added spacecraft power for T34D, added DC/DC electrical converter for space craft power, extendible exit cone for SRM-2 (T34D).

IUS Subsystem Elements



COMMONALITY

The use of common elements between the two stage vehicle and the twin-stage and twin-plus-spin vehicles is shown on the facing page. The SRM's are common elements and a high percentage of the avionics elements are common. Missions will require some new avionic functions, however, and therefore will require some new avionics units. New functions for the planetary missions include:

(1) The spinning third stage which will require a spin stage avionics unit.

(2) The need to minimize initation (wobble) of the spinning third stage which will require a Nutation Control Unit and an additional hydrazine system with reaction nozzles and associated hardware.

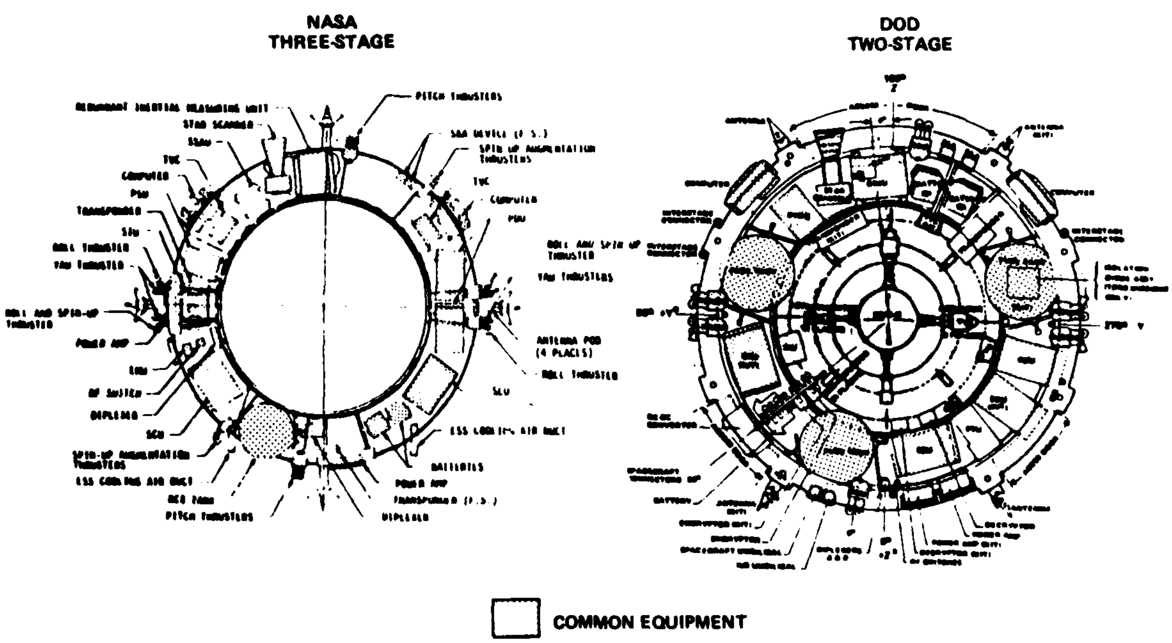
(3) A Spaceflight Tracking and Data Network compatible Tracking Telemetry and Control system which will require a Spaceflight Tracking and Data Network transponder.

The IUS structural components for two and three stage vehicles are not common so that performance can be maximized for each. The third stage structure and a portion of the second stage structure is constructed of an advanced graphite epoxy composite material.

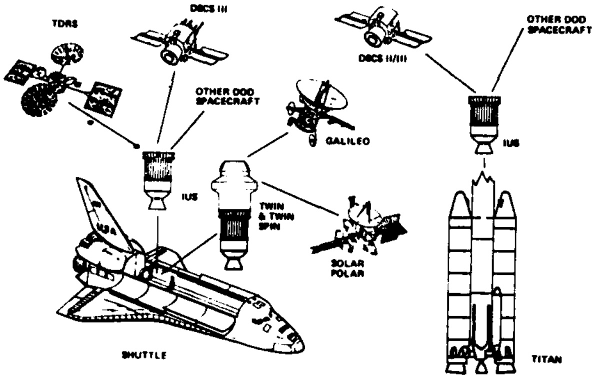
INERTIAL UPPER STAGE SPACECRAFT

The IUS vehicle, through the SINC program, is being integrated with many transitioning and new payloads. The design approach followed, through the evolution of a generic vehicle design, has resulted in minimum and manageable difficulties in accomodating this wide range of payloads and missions.

Common Equipment on Equipment Support Section



Inertial Upper Stage Spacecraft



LOADS AND ENVIRONMENTS

AVAILABILITY OF DESIGN REQUIREMENTS

The basic structural design loads have been unchanged since March 1978. The process for change, if necessary, requires nearly one year between the loads analysis by BAC, checking and validating by SD, PIC, etc., and negotiating and approving new criteria. Similarly, the acoustic and vibration environments have been unchanged since the developmental test vehicle (DTV) tests. Future Shuttle criteria revisions might require another DTV acoustic test.

The "environments" used in the thermal design of the generic IUS are readily available and include the natural environment, the induced environment, and the mission design environment.

CONSERVATISM OF DESIGN REQUIREMENTS

The design loads and environments are conservative in that extreme forcing functions coupled with an uncertainty factor of 1.5 and applying worst case load factors simultaneously result in large positive margins for expected loads. The vibration environments are conservative through the application of MIL-STD-1540A (6 db margin for qual enveloping of all response peaks and test duration larger than the flight environment).

The mission design environments include the design reference missions (DRM) timelines, Orbiter/payload orientations, and missions sequences. The IUS thermal design timelines encompass the combination of worst case times between significant events. This thermal design timeline has no relationship to reality but it does include all possibilities of event times. Also included in the thermal design timelines are a pre-launch environment and duration and an Orbiter abort sequence. The design considers Orbiter/payload orientations which vary widely from solar inertial with sun directly on the side of the IUS to solar inertial with sun on the end of the IUS. the IUS design also includes thermal control surfaces and materials properties which have been degraded.

RISK OF CHANGE

The Orbiter forcing function/model definition continues to change and perturb the design. Static load test may show capability less than the design requirements but this risk appears small.

Some acoustic predictions indicate that the low frequency acoustic environment may increase and invalidate some component qual results. This acoustic environment will be confirmed by the all-up Space Shuttle Main Engine motor firing later this year.

Loads & Environments

FACTOR	STRUCTURAL DESIGN REQUIREMENTS (LOADS)	ENVIRONMENTS (ACOUSTICS/VIBRATION/THERMAL/ETC)
AVAILABILITY OF DESIGN REQUIREMENTS	• SLOW PROCESS - LOADS DEVELOPED BY BOEING - USE ROCKWELL MATH MODES, FORCING FUNCTIONS - CHECKED BY RI - CHECKED BY SD/A - CHECKED BY MMC/PIC • ITERATIVE PROCESS	• ACOUSTICS – AVAILABLE IN 1978 • VIBRATION – IUS ENVIRONMENT DERIVED FROM ACOUSTICS ENVIRONMENT BY TEST IN 1978 • THERMAL – DERIVED FROM NATURAL ENVIRONMENTS (SOLAR FLUX, EARTH'S ABEDO, EARTH'S EMITTED ENERGY) DEFINED IN NASA TMX-64627
CONSERVATISM OF DESIGN REQUIREMENTS	• UNCERTAINTY FACTOR ON DYNAMIC LOADS – 1.5 • TIME PHASED LOADS APPROACH COULD SAVE WEIGHT • STRUCTURAL MARGINS FOR EARLY MISSIONS ARE HIGHER THAN FOR DOWNSTREAM MISSIONS (WT/CG DIFFERERNCES)	• MIL-STD-1540A TEST REQUIREMENTS PROVIDES CONSERVATISM • ENVIRONMENTS ACCOMMODATE WIDE RANGE OF PAYLOADS & MISSIONS
RISK OF CHANGE	• STILL CHANGING FORCING FUNCTIONS SHUTTLE MODELS • IUS STRUCTURAL TEST IN FUTURE	• SUBJECT TO CHANGE BY CAPTIVE FIRING RESULTS AND FLIGHT TESTS BUT CONSERVATIVE TEST APPROACH SHOULD MITIGATE RISK

MIL-STD-1540A TEST REQUIREMENTS

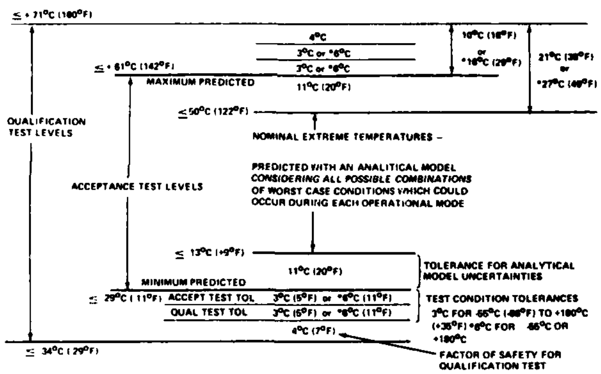
The "environments" used in the thermal design of the generic IUS include the natural environment, the induced environment, and the mission design environment. The natural environment includes the solar flux, the earth's albedo, and the earth's emitted energy. Also of importance is the space radiation environment and its effects upon thermal control materials. These natural environments are defined in NASA TMX-64627.

The IUS thermal design follows the guidelines in MIL-STD-1540A. The figure on

the facing page illustrates the thermal design margins specified by the MIL-STD. The 20°F (11°C) between the design requirement and acceptance test levels is to account for the pre-test thermal analysis uncertainties. The 18°F (10°C) between acceptance and qualification is to provide confidence that the component will perform at acceptance level for prolonged periods of time and to account for test uncertainties. Hence, the pre-test thermal design margins are 20°F.

The IUS thermal design environments are very conservative with large margins. The reasons being that the IUS must accommodate a large variety is not monitored because it is payload/mission dependent and must be evaluated for each payload type.

MIL-STD-1540A Test Requirements (Thermal)



IMPACT OF STRUCTURAL LOADS ON MISSION ASSURANCE

Conservatism in design is intended to compensate for a lack of confidence in design requirements such as structural loads. The amount of conservatism used for loads is a function of previous experience with the launch/landing system and the article being designed.

Initial conservatism in the two-stage structural design has protected the configuration from major redesign due to changing shuttle loads. The two-stage IUS system, except for orbiter interface loads, is designed using static load factor combinations which envelope the worst case loads factors derived from non-time-correlated dynamic response analyses. The dynamic analysis envelope includes a 1.5 uncertainty factor on dynamic response and is based on conservative forcing functions. It is believed that this procedures results in at least 25% conservatism in design loads. A less conservative approach using time-correlated loads is used at the orbiter interfaces.

In addition, the two-stage Airborne Support Equipment has been designed with a low response system which provides a "soft" suspension. This provides isolation and an insensitivity to changes in the orbiter dynamic forcing functions. The resulting Airborne Support equipment design is heavy and increases the shuttle cargo weight to accomplish two-stage missions. The low response frequencies may also adversely affect orbiter flight control system (FCS) stability margins.

The three-stage IUS is also being designed using static load factors which envelope the worst case non-time-correlated dynamic results but the uncertainty factor has been reduced to 1.0. The three-stage system will use the entire cargo weight capability of the shuttle and the lower uncertainty factor is used to reduce IUS inert weight and increase performance. No low response system is used for the three-stage in order to minimize ASE weight and hence this system may be sensitive to future shuttle forcing function changes. An orbiter flight control stability problem may also exist with this cargo since low frequency modes are present with this maximum cargo weight.

Impact of Structural Loads on Mission Assurance

Conservatism in design

- Compensation for changing inputs

Two-Stage

- 1.5 uncertainty factor used for 2-Stage dynamics analyses. Approximately 25% conservatism in design loads
- Forcing functions analyzed probably conservative
- Time-correlated dynamic loads envelope only used at orbiter interface
- "Soft Airborne Support Equipment suspension system design used to decouple spacecraft response from changing orbiter dynamics
- Results in high Airborne Support Equipment weight (shuttle cargo weight)
- Possible Flight Control System interaction

Three-Stage

- 1.0 uncertainty factor
- No "Soft" suspension system
- Not as conservative as 2-Stage
- Possible Flight Control System interaction

IMPACT OF ENVIRONMENTS ON MISSION ASSURANCE

The acoustic design environments are based on Titan IIIC data and are intended to envelope the Space Shuttle Vehicle and T34D. These environments have not changed since 1976 although several recent analyses

indicate that the low frequency environment should increase and the high frequency environment should decrease. If these changes were made, shock mounted equipment environments would increase while non-shock mounted equipment environments would decrease. Since shock mounted items are tested to MIL-STD-1540A minimum, this change should have no effect.

The avionics are designed for environments based on a full-scale developmental test vehicle (DTV) environmental test results with the application of MIL-STD-1540A margins of safety. This results in substantial conservatism since the DTV was more lightly loaded than the flight vehicle design and the complete set of cabling was not included in the test.

Impact of Environments on Mission Assurance

- Factors adversely affecting timeliness of information
  - Shuttle acoustic levels based on Titan III
  - No changes in acoustic level since 1976
- Conservatism in design
  - MIL-STD-1540A
  - Sensitive equipment shock mounted
  - Results in higher mounting weight

SAFETY REQUIREMENTS

The Safety Requirements for the IUS system are contained in "Safety Policy and Requirements for Payloads Using the Space Transportation System" (NASA 1976). The more significant requirements are shown on the chart on the facing page.

Safety Requirements

Safety policy and requirements for payloads using the space transportation system

Requirement	Impact on Design
• 2 Failure Tolerance	• Multiple Inhibits for Catastrophic Events
• In Flight Crew Monitoring/Safing	• Crew Panel Required
• Fracture Control of Structures	• Primary Structure and Support Bracketry
• Pressure Vessels	• Safety Factor of 4:1 or MIL-STD-1522 or Fracture Mechanics Program
• Hazardous Materials Control	• Select Non-toxic Non-flammable Materials
• Pyrotechnic Devices	• Use NSI-1 or MIL-STD-1512 with Additional Testing

DESIGN IMPACT FROM SAFETY REQUIREMENTS

Incorporation of the Structural Test System safety requirements into the design of the IUS system has resulted in cost and weight deltas. The impacts are summarized on the facing page. All of these requirements are currently incorporated into the design to the extend indicated.

Design Impact from Safety Requirements

- Increased Weight
  - 1.4 structural safety factor
  - Emergency landing loads
  - 4.0 safety factor for pressure vessels (optional to high cost analyses/tests)
  - Increased shielding for ordnance firing circuit
  - Redundant safety critical components
  - Additional inhibits for safety critical functions
- Increased cost
  - Addition of fracture mechanics control program; structures and tanks
  - Material selection and testing -Flammability/toxicity
  - Additional testing/qualification of pyrotechnic devices
  - Provisions for extra vehicular activity compatibility
  - Waiver processing for non-compliance with selected requirements

DOD/STS SAFETY CERTIFICATION PROCESS

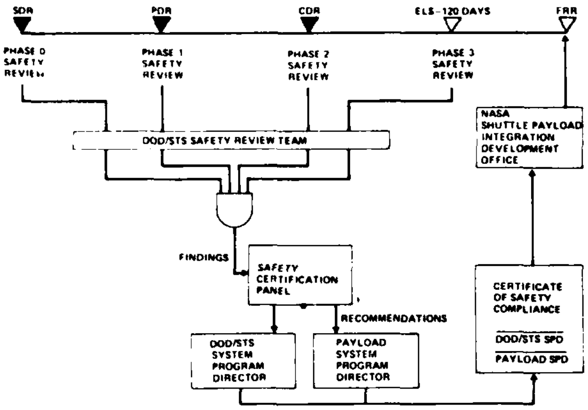
The DOD/STS Safety Certification process, as depicted on this chart, is set forth in SAMSO (SD) regulation 127-4 dated 30 November 1978.

A similar process exists for NASA and commercial payloads, as required by the NASA *Safety Policy and Requirements for* Payloads using the Space Transportation System (STS). Concurrence and approval of the NASA Safety Review Team is provided directly to the payload organization and documented in the minutes following each Safety Review. The safety compliance data package and signed certification by the payload organization, certifying the compliance of the payload with the Safety Policy requirements, is provided to NASA 30 days prior to delivery of the payload to the launch site.

Safety Certification Process

- DOD Payloads
  - 4 incremental safety reviews - DOD safety review team
    - NASA safety represented on DOD team
    - System program director signs certificate of safety compliance based on recommendations of DOD/STS safety certification panel
- Non-DOD Payloads
  - *4 incremental safety reviews - NASA safety review team (JSC)*
  - 4 separate ground safety reviews at KSC

DOD/STS Safety Certification Process



Summary

STRUCTURAL DESIGN	ASSESSMENT
• STRUCTURAL DESIGN REQUIREMENTS	• FORCING FUNCTIONS CONTINUING TO CHANGE • DYNAMIC LOAD UNCERTAINTY FACTOR GREATER FOR TWO STAGE VEHICLE THAN THREE STAGE VEHICLE (1.5 VS 1.0)
• PREDICTED ENVIRONMENTS	• OK WITH CIRCA 1976 ACOUSTICS DATA IS IT GOOD? • CONSERVATIVE THERMAL APPROACH • CONSERVATIVE TEST APPROACH
• MEASURED ENVIRONMENTS	• DEPENDING UPON EARLY SHUTTLE FLIGHTS TO CONFIRM PAYLOAD BAY ENVIRONMENTS
• DIFFERENCES IN AF & NASA SPECIFICATIONS	• MAJOR DIFFERENCES IN PARTS SPECIFICATIONS AND TEST CRITERIA
• SAFETY REQUIREMENTS	• SOLID PLAN - WELL INTEGRATED INTO DESIGN • JOINT AF/NASA CERTIFICATION PROCESS
• MULTIPLE PAYLOAD CARGO	• INTERACTION WITH ORBITER FCS DURING ENTRY AND DESCENT A CONCERN
• REUSEABILITY REQUIREMENTS	• REUSEABLE ELEMENTS (AIRBORNE SUPPORT EQUIPMENT) SUBJECT TO RECYCLE REFURBISHMENT

SUMMARY

The overall approach taken in design of IUS is conservative with good margin provided for through the use of uncertainty factors on loads and environments. Additional conservatism inherent because generic vehicle must be capable of wide range of missions, high reliability parts, MIL-STD-1540A test approach, and high level of redundancy. However, all of this conservatism has resulted in increased weight which has degraded payload performance capability.

Some fundamental orbiter to IUS interface concerns still remain which dictate that the highly conservative approach is probably appropriate:

Changing orbiter structural models and dynamic forcing functions

Potential coupling of IUS system structural dynamics and orbiter flight control system

Confirmation of payload bay environments through flight test data analysis

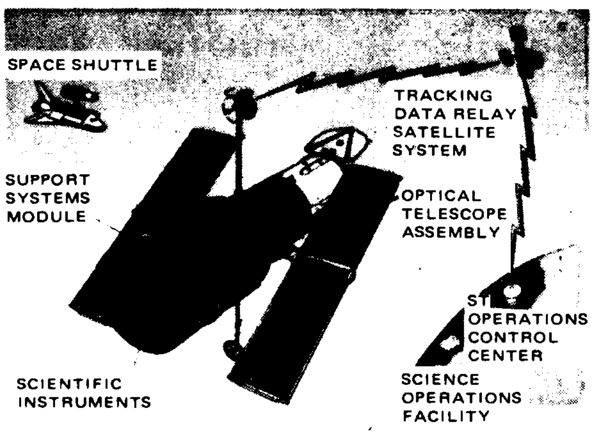
DESIGNING SPACE TELESCOPE FOR THE SHUTTLE ERA

Marne L. Mercer
Space Telescope Program
Lockheed Missiles & Space Company
ST/STS Interface Manager

DESIGNING SPACE TELESCOPE FOR THE SHUTTLE ERA

Ten seconds in the marriage of the Space Telescope to the shuttle produce major problems for the Space Telescope designers. I will talk about these ten seconds, why they are troublesome, what Space Telescope is doing about the problems and what the Space Shuttle should do about them. But first a few words about the Space Telescope. It will be an astronomical observatory in a 300 nautical mile orbit around the earth. It is 42 feet long and 14 feet in diameter and weighs 23,000 pounds. It will see seven times as far as the best earth observatory. It has an 8 foot diameter primary mirror and five scientific instruments, each about the size of a telephone booth. The pointing accuracy requirement is one hundredth of an arc second. In other words, this is a large, high precision vehicle.

SPACE TELESCOPE SYSTEM



And now for the troublesome ten seconds. In December 1983, a test director in Florida will push a button and over six million pounds of thrust will lift the Space Shuttle and the Space Telescope off the pad. This thunderous event does two things to the Space Telescope. It produces most of the structural design loads and all of the vibro-acoustic design environments. Where do we get the design loads? The Space Telescope to Space Transportation System Payload Integration Plan tells us.

TROUBLES FOR SPACE TELESCOPE DESIGNERS

- STRUCTURAL DESIGN LOADS
- VIBRO-ACOUSTIC DESIGN ENVIRONMENTS

EXTRACTS FROM PARA. 6.1 OF STS/ST PAYLOAD INTEGRATION PLAN

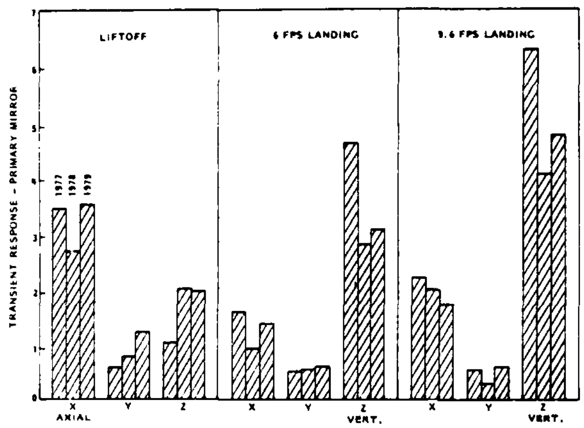
"...DESIGN SHALL BE BASED UPON COUPLED DYNAMIC AND QUASISTATIC ANALYSIS PERFORMED USING UPDATED PAYLOAD AND SHUTTLE MODELS."

"THE PAYLOAD IS RESPONSIBLE FOR APPLYING APPROPRIATE CONSERVATISM TO THE LOADS TO ACCOUNT FOR ANTICIPATED MODEL AND FORCING FUNCTION UPDATES.

"...THE RESPONSIBILITY FOR PAYLOAD COMPATIBILITY WITH THE FINAL FLIGHT LOADS REMAINS WITH THE PAYLOAD.

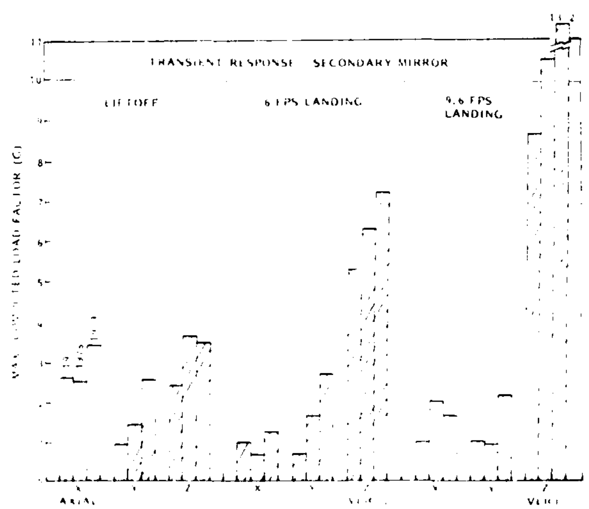
There's the rub. What is "appropriate conservatism" to "account for anticipated updates" to assure compatibility with the "final flight loads"? We have run three load cycles (in 1977, 78 and 79) for the Space Telescope and the results provide some guidance on how loads vary with different models and different transients. Here are the results for the primary mirror for the lift-off and two landing conditions. The maximum computed load factor for three orthogonal axes are plotted for each load cycle. The variations are thus graphically portrayed. We did this to help us establish an appropriate "variability factor" to apply to computed load factors in order to establish design load factors. The objective of these design load factors is that they be "compatible with the final flight loads" which will be computed three years from now.

TRANSIENT RESPONSE · PRIMARY MIRROR

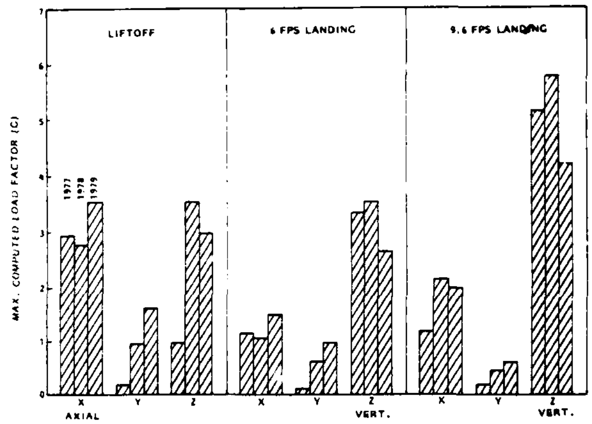


Similar variations but different magnitude load factors were computed for the secondary mirror and scientific instruments. After studying our results and the results of other programs, we decided to apply a variability factor of 1.6 to the latest (1979) computed load factors to establish design load factors for the ST. After discussions and independent evaluations, Marshall Space Flight Center concurred with this factor.

TRANSIENT RESPONSE · SECONDARY MIRROR

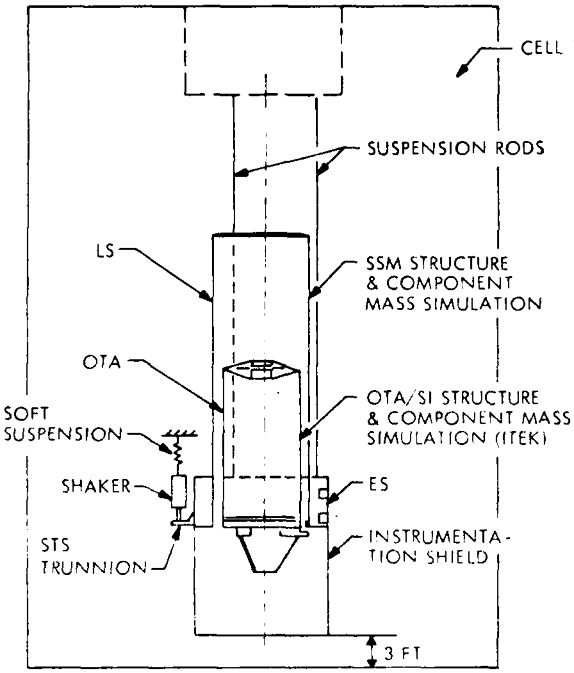


TRANSIENT RESPONSE
MAJOR SCIENTIFIC INSTRUMENTS



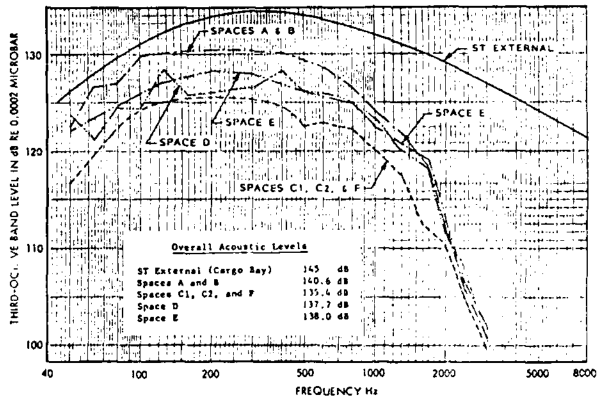
The other shuttle environment which is a major design driver is the vibro-acoustic environment of lift-off. This affects the structural design in terms of additional lift-off loads. Even more significant, it is a primary design and test environment for all spacecraft components. For these reasons, early in the program, Lockheed ran an acoustic test of a full scale dynamic test vehicle with simulated components. This is the test set-up. The vehicle was supported by a low frequency suspension system and subjected to the acoustic spectrum specified in the ICD. It was also subjected to random vibration inputs at the trunnions. These contributed very little to the total random response of the ST elements.

VIBRO-ACOUSTIC TEST SET-UP



The test provided design acoustic and random vibration levels for the various zones of the ST vehicle. This chart shows the applied spectrum (145 db overall) and the various internal acoustic levels. Not shown are the random vibration design levels for eight different zones. The final pre-flight verification of these environments will be an acoustic test of the flight vehicle to maximum flight acoustic levels. Prior to this, we presume that the Space Shuttle will have comprehensive verification of cargo bay acoustics from early flight instrumentation.

The final pre-flight verification of the structural design loads from the ST side will be an ST/shuttle coupled analysis using an ST model which has been verified by model tests of the ST flight vehicle. Prior to this, we presume that Space Shuttle will have comprehensive verification of the shuttle model and forcing functions from ground and early flight instrumentation.



CONCLUSIONS

IN DESIGNING SPACE TELESCOPE FOR THE SHUTTLE ERA

- TWO SIGNIFICANT RISKS TO SUCCESS
  - UNANTICIPATED STRUCTURAL LOADS
  - UNANTICIPATED VIBRO-ACOUSTIC ENVIRONMENTS
- ELIMINATION OF RISKS
  - ANALYTICAL AND TEST VERIFICATION OF ST AND SHUTTLE MODELS
  - EARLY FLIGHT VERIFICATION OF SHUTTLE CARGO BAY ACOUSTIC AND LOADING ENVIRONMENTS

DESIGNING FOR THE SHUTTLE ERA MISSION ASSURANCE IMPACTS OF MULTI-PAYLOAD CARGOS

Paul A. Christensen
Martin Marietta Corporation

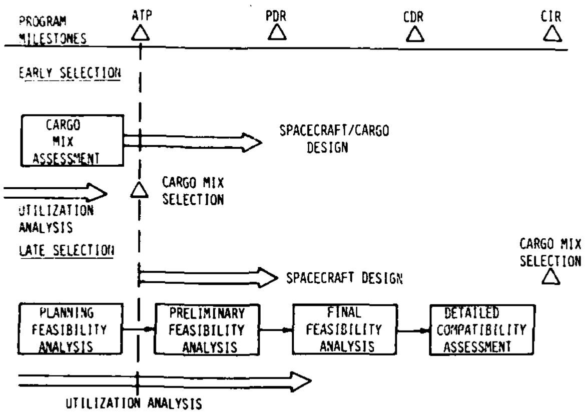
REASONS FOR MULTI-PAYLOAD CARGOS

- o PMD 35171F

  "TO TAKE MAXIMUM ADVANTAGE THE MULTIPLE PAYLOAD AND MIXED CARGO CAPABILITIES OF THE SPACE SHUTTLE"

- o COST
- o CONSERVATION OF NATIONAL RESOURCES

ESTABLISHING THE CARGO MIX



IMPACT OF EARLY MIX SELECTION

- o CARGO DESIGN PROCEEDS IN PARALLEL WITH S/C DESIGN AND CARGO ELEMENT INTEGRATION
- o DISCIPLINED CONTROL OF COMPATIBILITY AMONG CARGO ELEMENTS
- o INTERACTIVE COST/SCHEDULE RISK AMONG CARGO ELEMENTS
- o LIMITED LAUNCH OPPORTUNITIES

IMPACT OF LATE CARGO SELECTION

- o INCREASED LAUNCH OPPORTUNITIES FOR INDIVIDUAL PAYLOADS
- o HIGHER RISK OF DESIGN INCOMPATIBILITIES
- o POSSIBLE DESIGN CONSTRAINTS TO ACCOMMODATE FLEXIBILITY
- o COST/SCHEDULE RISK OF CARGO ELEMENTS UNCOUPLED DURING DESIGN PHASE

MULTI-PAYLOAD CARGO IMPACTS ON MISSION ASSURANCE

- o POTENTIAL COMPROMISE OF DESIGN AND TEST MARGINS TO ACCOMMODATE CARGO COMPLEMENT
- o DESIGN MAY COMPROMISE MISSION CAPABILITY
  - POTENTIAL MIXERS MUST BE INSENSITIVE TO ENVIRONMENT
  - POTENTIAL MIXERS MUST MINIMIZE IMPACT ON ENVIRONMENT
- o SCHEDULE OF OTHER CARGO ELEMENT MAY COMPROMISE NORMAL PRELAUNCH SEQUENCE
- o FAILURE OF ONE CARGO ELEMENT MAY IMPACT MISSION OF ACCOMPANYING ELEMENTS
- o ADDITIONAL INTERFACES PROVIDES ADDITIONAL RISK

PAUL DICK
GENERAL ELECTRIC COMPANY SPACE DIVISION

Ladies and Gentlemen, or shall I say persons? Welcome to the 1980 Mission Assurance Conference Session "Effective Failure Analysis in the Development Cycle". I am your Session Chairman. My affiliations are Paul Dick, System Effectiveness Manager, General Electric Company Space Division.

Before I introduce the distinguished four speakers, let me tell you why we are doing this program for you. The value of failure analysis in the development cycle of a high reliability product is not challenged by anyone other than an occasional overspent, very late in delivery program management type who has many serious worries on his mind. The majority of the population recognizes its value and benefit to product reliability and long life.

When we enter into deeper discussions on the subject of failure analysis, several key administrative, operational, application, authority, responsibility, and customer requirements enter into the picture. Some of these popular issues or questions include:

- Where should responsibility lie for Failure Analysis in a project organization?

- What is and should be the role of the customer and his participation in the failure analysis process?

- What is the value of failure analysis to a program's success and schedule?

- Are there ways to profit from the results of a failure analysis on current and future programs?

- How effective is failure analysis to assure lasting corrective action?

- What types of methods can be used for exchanging problem and corrective action information interchanges between various organizations on items of common interest?

- How adequate are customer specifications, requirements, and work statements on failure analysis (including MIL-Specs, NASA-Specs, etc. where applicable)?

- What recommended improvements are advised?

- Which are the practical methods of performing FMEA?

- What is and should be the degree of designer involvement in FMEA?

- How can sneak circuit analysis be used effectively?

- How does one assure effective management of a single point failure and control of critical characteristics?

I've asked each of the speakers that I will soon introduce to try and cover a few of these points in his presentation materials which I am sure you will enjoy and find interesting. Our speakers, in advance of their individual introductions, are two user types and two customer support types alphabetically as follows:

Mr. Edgar Doyle, Manager
Quick Reaction Failure Analysis
RADC

Mr. Ronald Hanni
Senior Reliability Engineer
Ford Aerospace & Communications Corp.

Mr. Joseph R. Howell
System Effectiveness Engineer
Aerospace Corporation

Mr. Rick Simon
Process Control Manager
General Electric Space Division

To keep it fair geographically wise after I get off the stage, I've set the rotation as follows:

1. An East Coast Aerospace Contractor's View (Mr. Simon)

2. A West Coast Aerospace Contractor's View (Mr. Hanni)

3. An East Coast Customer's Agency View (Mr. Doyle)

4. A West Coast Customer's Agency View (Mr. Howell)

I'll introduce each speaker and let him do his thing for 20-25 minutes each. I ask

that you keep your questions until after the last speaker is completed and I turn the discussion over to the audience. However, to maintain some rules of order, I sincerely ask that you please fill-in the questionnaire cards available in the audience and send them up to me as each speaker gets finished. I will collect, catalog, and ready these questions for presentation to our panel or a particular speaker if so noted on the card for the discussion period after the last presenter.

I promise that we will try and have all questions submitted answered, time permitting, at this meeting. Those not addressed, will be assigned to various panel members by me to have them respond via letter to you, so please put your name and address on the questionnaire card unless it is so explosive that you'd like to remain anonymous.

When we run out of question cards, you may ask questions from the audience. Of course, once a question is read from a card and answered up here, you may want to raise your hand out there and be recognized for further discussion, whether it was your question or not being discussed.

This panel is vitally interested in what you think, need, and suggest, so please be part of the interchange after the last speaker. We need your help as we the panel will present a report to the organizing committee at the end of this conference to see where we go next and your comments are vital so that it is not just what us five "Super Stars" think, need, and have suggested.

At this point, I say thank you for your patience to hearing me rattle on and I with pleasure will now introduce our four distinguished speakers.

EFFECTIVE FAILURE ANALYSIS IN THE DEVELOPMENT CYCLE

Ronald G. Hanni
Ford Aerospace And Communications Corporation
Western Development Laboratories
Palo Alto, Calif.

Introduction

The role of failure analysis is to positively impact the probability of success (P_s) of a program by analyzing failures and providing the information necessary to take effective corrective action, reducing the likelihood of subsequent similar failures. Well executed failure analysis will fulfill that role. This paper will outline the structure of the failure analysis effort as performed on a typical program, and the benefits derived therefrom.

Effort Level and Benefit

In considering the structure of failure analysis it becomes important to realize that in effectively managed organizations, much cross-program impact of and benefit from failure analysis occurs due to the commonalities of technology being utilized amongst the various programs. Often technology or hardware developed for one program becomes an "off the shelf" item for subsequent programs. Hence, effective failure analysis begins prior to a contract award and may affect more than one program. Additionally, development work is often performed during the course of a program in order to solve problems encountered or to improve the end product.

These ideas are displayed and developed further in Figure 1 which provides a representation of development work and failure analysis effort vs time during a typical program. There is an underlying level of general product development work and associated failure analysis which is always being performed. As the technological requirements for a program are clarified during the pre-proposal and proposal efforts, goal orientated development begins. This focused development accelerates greatly at the award of the contract and during the prototype phase. As processes, designs and hardware mature through the production phase, the development effort declines to the background level.

The positive impact of failure analysis becomes important in the early stages of a program, especially in the proposal and prototype phases when new processes and components are being used. Here failures can be analyzed and documented yielding appropriate corrective actions which are instituted to prevent recurrence of similar failures. At this point failure analysis can detect problems in design, process, part application, assembly and test.

An example of effective failure analysis and ensuing corrective action occurring early in a program is provided by lot oriented migratory gold resistive short failures. During prototype and flight powered thermal testing of comm subsystem front end modules, intermittent base emitter shorts of an r.f. transistor were encountered. After removal, electrical tests found the transistors to be good. During powered monitored thermal cycling and cold temperature soaks, it was found that intermittent base-emitter shorts could be produced. After a short time these intermittents became solid failures. Subsequent S.E.M. and X-ray spectographic analysis of the transistors identified the failure to be due to migratory gold resistive shorts as shown in Figures 2 through 4.

These shorts formed between the unglassivated gold metallization fingers having a spacing of 3u under a combination of high package moisture content, bias and time at cold temperatures. The requirement of a high moisture content in the packages and the occurrence of multiple failures made the conclusion that the problem was lot oriented inescapable. Due to the non-availability of these transistors, and the presence of an acceptable screened substitute transistor type in flight stores, replacement was made with the new transistor type. In this instance, effective failure analysis and appropriate corrective actions avoided a serious program impact and prevented repetitive failures.

During the production cycle of a program, failure analysis continues to play an important role in the success of a program. During the production cycle the design has been proven,flight quality parts are

being used, and well controlled assembly and test procedures are being utilized. A failure at this point can represent an oversight of design, assembly or test or inherent defects in parts which have successfully completed screening.

Organization

To be effective, failure analysis should be performed by a dedicated support service which is independent of design, manufacturing, and test organizations. This support organization should have full technical responsibility for the conduct of the failure analysis. When critical failures occur with large impact potentials a "task force" approach is often employed with the Program Office monitoring the analysis, providing managerial direction and allocating company resources as needed. The Program Office also provides high level customer interface in these circumstances. This organization is represented in Figure 5.

Customer participation is normally limited to review of the results of the failure analysis and corrective actions implemented. However, at high levels of criticality and impact potential the customer is routinely involved in the form of consultant and real time monitoring functions interfacing through the Program Office. Customer requirements concerning failure analysis contain the requirement that closed loop failure analysis be performed when failures occur at or after the first powered module level test. Additionally, failures occurring at system level tests are reportable to the customer within 24 hours. The customer is provided copies of the failure analysis reports for review.

Failure analysis is performed to cost effective internal procedures, which have been developed over the course of several programs. These procedures are generalized guidelines which require that experienced competent analysts evaluate the data and hypothesis at each step of the analysis. These procedures essentially require that the failure be confirmed, the failure isolated, and the cause determined. The analysis is fully documented.

Schedule Impact

The impact of failure analysis on a program schedule varies with the point in the program when the failure occurs and with the combination of the failure criticality and cause. Failures which occur early in the design phase of a program are the most productive failures to occur. Effective failure analysis and corrective action can prevent recurrence and prevent schedule impact at a later time when schedule recovery is more difficult. As the program progresses, the impact of failure analysis on a program usually becomes more severe as there are fewer opportunities to recover from the consequences of a failure - especially where extensive rework and/or retrofit is involved.

Due to a recently instituted procedure, some additional positive schedule impact occurs, as shown in Figure 6. The functional electrical condition of electronic parts suspected of having caused a failure are determined within 24 hours of receipt by the failure analysis laboratory. Meanwhile no rework or repair is performed until it is determined if the suspect part is good or bad. If bad, rework and repair proceeds. If good, further troubleshooting is performed by MRB direction. This positively impacts schedule by preventing rework which may not solve the problem and which may need to be repeated. This also prevents degradation of hardware by repeated rework/repair cycles.

Additional benefit to a program's success and schedule can be realized by application of failure analysis technology, especially non-destructive techniques, to material, part, and hardware evaluation. Failure analysis can sometimes be performed in-situ, gathering enough information to decide probable causes of failure and to whether or not to continue with the test which discovered the failure.

Figure 7 illustrates an example where a non-destructive technique, X-ray radiography, provided an answer as to the cause of a failure occurring during thermal cycling. The object shown in the figure is a quarter inch termination load resistor whose bifurcated contact had been soldered to a stripline board. The board is part of an antenna feed array consisting of three stripline layers with aluminum honeycomb and feedhorns. The assembly failed in this one element (of approximately 40) after 194 thermal cycles of a planned test of 400 cycles. One choice presented was to halt the test, disassemble the feedboards, remove the

resistor, perform failure analysis, and then re-assemble the feedboard in order to resume the test. Another choice presented was to X-ray the assembly in the failed area to determine if the cause could be found. From the X-ray it was apparent that the cause of the failure was not a lot related failure of the resistor, but a mechanical overstress which probably occurred during assembly. It was decided that the test could be resumed without repair, and without significant schedule impact. As corrective actions, all flight feedboard assemblies were X-rayed to inspect for any discrepant conditions occurring in the resistor assemblies. The assembly, test, and inspection personnel were cautioned about careful handling and inspection using this case as an example. Here schedule improvement resulted from applying a non-destructive technique to perform effective failure analysis.

Closing the Loop

The results of the failure analysis are integrated into current programs via report dissemination and corrective actions. Report distribution includes representative of program offices, customer organizations, design engineering, line management and part procuring activities. This is shown in Figure 8. Monthly FRB's (Failure Review Boards) are convened which review problems, the results of failure analysis and the effectiveness of corrective actions. This is in addition to the real time monitoring activities of critical failures by the applicable program office and customer representatives. Quarterly reports also include a Failure Summary Report. Failure analysis information is additionally entered into a computerized index which summarizes the results of the failure analysis and allows access by problem reference numbers, part numbers, and programs. Cross-program information dissemination is accomplished due to commonalities of all involved parties except program offices and customer organizations. Representatives of all program offices are included on failure analysis report distributions. External information exchange is accomplished in a real time basis through customer organizations, which frequently monitor more than one program and more than one contractor, and through part vendor contacts.

It is an internal policy that vendors are routinely notified of problems encountered in failure analysis where vendors' manufacturing processes are the cause of or a contributor to the failure of a part. This frequently occurs through meetings with vendor representatives and their technical staff. Occasionally, vendor "education" occurs through laboratory demonstration of problems and defects, followed by aid to vendors in their product development efforts and close monitoring of vendors manufacturing lines. This requires a large amount of goodwill between the vendor and the contractor.

In appropriate cases the GIDEP system is used to alert the industry to serious part problems. Symposia, professional society meetings, and trade publications are used to further disseminate the information. However, internal budgetary and procedural constraints limit the effectiveness of these systems.

Program corrective actions include rework, retrofit, and evaluation cycles, as well as procedural and procurement specification revisions. Lasting corrective action is organizationally and timewise a problem distinct from failure analysis. Lasting corrective action occurs as a result of changes implemented in design, manufacturing, test and procurement organizations. It is the responsibility of those organizations to make appropriate changes in response to problems and to ensure their future applicability. The changes are subject to review by program offices, customer organizations and reliability/quality control organizations. Other reliability tools such as FMEA (Failure Modes and Effects Analysis),CARR (Circuit Analysis Reliability Report), and DPA (Destructive Physical Analysis) systems monitor lasting corrective action effectiveness. These reliability analyses are performed at various phases of each individual program.

An example of lasting corrective action is illustrated by a conductive particle inclusion problem. Loose conductive particles have caused failures by shorting internal lead wires to die scribe moats in semiconductor devices with the failures normally occuring during vibration. Figure 9 shows an example of failure caused by AuSn lid sealing material while Figure 10 shows a failure caused by ex-

traneous aluminum slivers generated during wire bonding. These devices successfully passed all the screening requirements including pre-cap, X-ray, PIND, and 672 hrs of burn-in.

As a result of these failure analyses, considerable additional DPA effort was performed on all lots received from this vendor. Meetings with the vendor were held which involved technical sessions demonstrating the presence of included particles in their devices,,and techniques for particle detection and identification. After the vendor accepted that a problem existed, large amounts of engineering effort were expended to determine the cause of the AuSn material and the source of the Al slivers. Corrective actions included changes in the vendor's processing and inspection procedures and in the procurement specifications. The effectiveness of these measures was verified by analysis of evaluation samples. Concurrently, with the problem identification and correction activities, heightened preseal inspection and DPA efforts were performed. The lasting effectiveness of these changes are monitored during DPA.

Improvements

A need exists for greater availability of detailed failure analysis procedure/technique information and training sessions. This may be alleviated by a new technical society which is in the formative stages, the International Society for Testing and Failure Analysis (ISTFA). Targeted concise summaries of failure experience concerning specific failure modes, analytical techniques, and specific part or vendor devices would also be helpful.

Conclusions

Effective failure analysis will positively impact the probability of success of a program by reducing the likelihood of repetitive similar failures. An organizational structure, providing for an independent support service, to achieve the goal of effective failure analysis has been illustrated. Failure analysis has been shown to be extremely important during the development phases of a program, as evidenced by the level of effort required and the positive impact potential. Effective failure analysis has been shown to result in schedule improvements in some instances. Examples of failure analyses and their corrective actions have been given. Some areas of recommended improvements have been outlined.

Figure 1. Development and Failure Analysis levels of effort vs time.

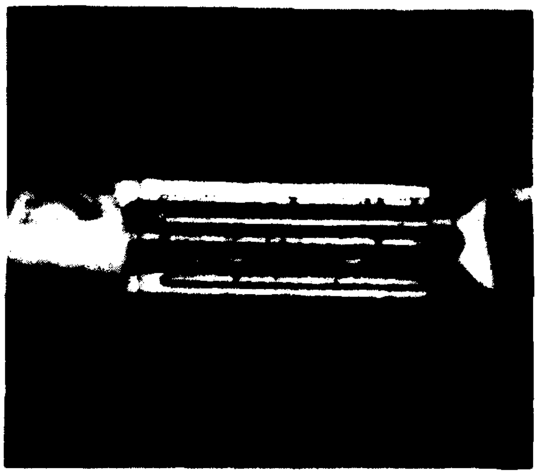


Figure 2. Overall view of the active area of r.f. transistor die. The darkening of the base finger is indicative of electrochemical action on the metallization.

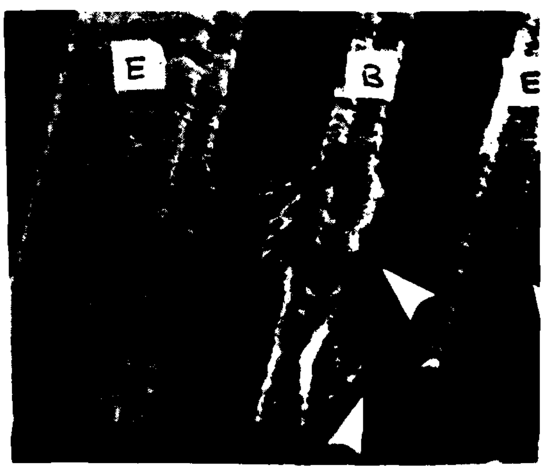


Figure 3. Arrows indicate location of sites of electromigration on die pictured in Figure 2. The metallization fingers are identified by function.

Figure 4. Arrows indicate location of electromigrated metal shorting the emitter to the base on another transistor of the type illustrated in Figure 2.

Figure 5. Organizational Chart

Figure 6. Failure Analysis Flow Chart.

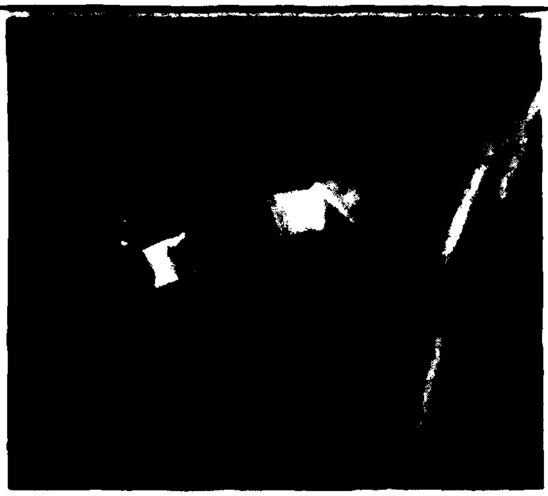


Figure 7. Enlarged radiograph of mechanically overstressed termination resistor which failed during thermal cycling.

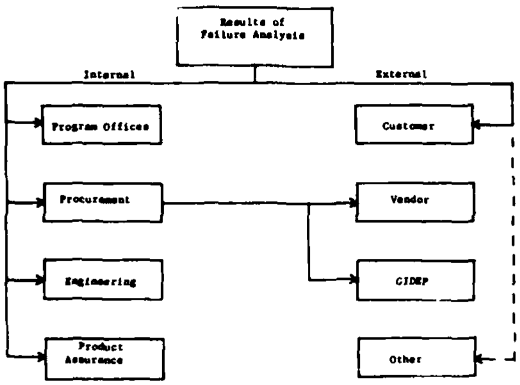


Figure 8. Distribution of Failure Analysis Results.

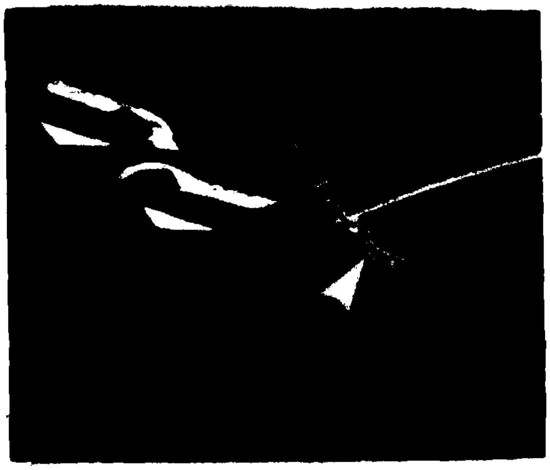


Figure 9. Arrow indicates a strand and ball of gold-tin lid seal eutectic shorting a compensation lead to the die scribe moat (electrically V^-) of an operational amplifier.

Figure 10. Arrows indicate aluminum slivers shorting the Vcc supply lead to the die moat (electrically GND) of a quad comparator.

EFFECTIVE FAILURE ANALYSIS IN THE DEVELOPMENT CYCLE

RICHARD C. SIMON
GENERAL ELECTRIC SPACE DIVISION - VALLEY FORGE, PA.

OVERVIEW -- SYNOPSIS OF PRESENTATION

The series of vu-graphs which comprise this presentation are divided into the following seven subjects:

- Value of failure analysis to a program's success and schedule
- Profiting from failure analysis results
- Failure analysis effectiveness to assure lasting corrective action
- Exchanging problem and corrective action information
- Recommended improvements
- Organizational responsibility for failure analysis
- Customer's role in failure analysis

The following sections of this paper elaborate on each of the above subjects.

VALUE OF FAILURE ANALYSIS TO A PROGRAM'S SUCCESS AND SCHEDULE

It is the author's belief that the success of a program is greatly enhanced by effective failure analysis. However, it must be noted that a program's schedule will be negatively impacted by failure analysis results if costly and time-consuming retrofitting and/or design changes are necessary.

PROFITING FROM FAILURE ANALYSIS RESULTS

The major thrust for an effective failure analysis is to identify the cause of failure so that appropriate corrective action can be identified and implemented in order to preclude failure recurrency. To this regard, action items are assigned to the operation that has the resources to accomplish the necessary effort. Sometimes, this will include return of the failed item to a vendor's facility for more extensive analysis of identifying the failure mode. When action items that cannot be completed immediately are assigned, an initial Failure Analysis Report is published. Results of corrective actions are published in one or more supplements.

A successful method utilized by General Electric Space Division to apply "lessons-learned" from the failure is to widely communicate the results through extensive distribution of the Failure Analysis Report. Since we utilize a matrix management concept at General Electric, Product Assurance Project Engineers on all programs are given copies of all Failure Analysis Reports. Functional management in Product Assurance, Manufacturing, and Engineering are likewise added to distribution. Each distribution list is tailored to include failure analysis participants, other concerned individuals, and customer/vendor representatives, as required.

The Corrective Action Board (CAB) which meets monthly is another vehicle utilized to assure that failure analysis results are appropriately implemented. In accordance with MIL-STD-1520A, senior functional managers in Quality, Engineering, and Manufacturing, meet monthly to discuss, among other items, those failure analyses that are of significance to the Space Division. Customers and Program Offices send observers to these CAB meetings and again, the minutes are widely distributed to key personnel.

A final vehicle to assure that failure analysis results are effectively implemented is through a program unique Failure Review Board (FRB). The FRB is convened monthly and consists of extensive discussions between customer and contractor personnel on significant nonconformance reports and on all program Failure Analysis Reports. These discussions involve the individual Quality Control Engineer who has responsibility for the nonconforming item under discussion and the Failure Analysis Chairman or Failure Analysis Engineer who has conducted the failure

analysis under discussion.

FAILURE ANALYSIS EFFECTIVENESS TO ASSURE LASTING CORRECTIVE ACTION

Three different illustrative examples are utilized to depict three different types of failure modes associated with component piece parts. Of specific interest is the diversity of failure analysis participants.

On one program, an intermittent logic circuit was detected during low temperature testing of a complex printed circuit board. The suspect failure area focused on two flatpack IC's. Solder joints appeared normal. During failure troubleshooting/investigation, it was noted that slight pressure on a diode located on the other side of the PCB, exactly opposite the two suspect IC's, resulted in duplication of the failure mode. Further analysis indicated that a region of chipped paint on the diode located exactly on top of a plated through hole, permitted contact between the grounded end of the diode and a pin on one of the IC's. It was deduced that contraction of the conformal coating surrounding the diode at low temperature had resulted in contact between the metal body of the diode and the plated through hole. Corrective action was to revise the GE Specification to call for metal cased parts which are mounted over printed circuits to be enclosed in transparent insulation. This problem has not recurred thus verifying the effectiveness of the corrective action. Failure analysis participants included a Quality Control Engineer, Design Engineer, Packaging Engineer, and Materials and Processes personnel.

Recently, a power controller failed due to excessive output from the voltage divider on a printed wire board. The problem was traced to a resistor which was returned to the manufacturer for further analysis. It was concluded that there was contamination consisting of a copper fiber internal to the resistor introduced by a copper brush used to clean the cavity of the production mold. The resistor vendor checked all production molds and there was no evidence of any copper cleaning tools. Soft hair brushes only may be used for cleaning per standard operating procedures. Corrective action consisted of cautioning operators against using any other cleaning tool. Failure analysis participants included a Parts Engineer, Quality Control Engineer, Design Engineer, the Vendor's Product Engineer and Quality Control Engineer, and an outside laboratory, utilized by the vendor to identify the foreign material inside the resistor.

A third failure analysis involving component piece parts occurred when Siliconix FET switches, located on a Safe Hold Electronics (SHE) Control Amplifier PWB, failed to open and close. The presence of corroded aluminum wires and bonding pads were found inside the FET switch. X-ray microprobe, x-ray mapping, and residual gas analysis by GE and Siliconix laboratory consultants verified that the corrosion was due to the presence of chlorine inside the FET switch. Intensive analysis was performed to determine how the chlorine was introduced into the switch. It was concluded that the chlorine entered the switch during board cleaning through a microcrack in the ceramic body of the switch introduced during lead forming at GE. The problem was traced to a specific operator who was reinstructed in the use of the lead forming tool. All FET switches installed by this operator were replaced and inspectors were made aware of the problem and are monitoring for recurrence. Failure analysis participants included a Parts Engineer, Quality Control Engineer, Process Control Engineer, Manufacturing Engineer, the Parts Testing Lab, Materials and Processes personnel, the Siliconix Failure Analysis Engineer, two outside labs utilized by GE and a third lab utilized by Siliconix.

On each failure analysis, all participants' efforts are coordinated by a Failure Analysis Engineer with the entire project managed by the Failure Analysis Board Chairman.

EXCHANGING PROBLEM AND CORRECTIVE ACTION INFORMATION

Besides the methods discussed above -- wide distribution of failure analysis reports, and regular Corrective Action Board and Failure Review Board meetings -- several other vehicles provide positive means for exchanging problem and corrective action information. By far the most familiar to members of the Aerospace community is the GIDEP Alert System. The major problems with GIDEP though are the potential legal ramifications which do provide both a conscious and subconscious screen into the quality/quantity of GIDEP Alerts.

Other customer contacts, both written and verbal, are also useful in exchanging information. A recent example whereby information was obtained rapidly from many different sources was the Reynolds aluminum problem. Besides the communications received from various governmental agencies, Reynolds personnel themselves provided much information and guidance.

An internal method used to communicate Quality related information at General Electric's Space Division is the Product Quality Alert (PQA). These Alerts are issued periodically based on information obtained from a variety of sources including GIDEP Alerts and the results of failure analyses. An example of a Product Quality Alert resulting from a failure analysis was a temperature sensor (thermistor) that was short circuited due to an internal reflow of low melting point solder which shorted both thermistor contacts. This occurred during soldering at GE of the short thermistor leads to extensions. The Product Quality Alert which was subsequently issued defined the corrective actions taken on the specific program involved as follows: pre and post-pot resistance checks; mandatory use of heat sinks on thermistor leads; planning cautions to minimize soldering application times; and a post-pot isolation check between wire leads and the aluminum base plate. Of extreme importance was the closing statement of the Alert: "ALL OTHER PROGRAMS UTILIZING THERMISTOR-TYPE TEMPERATURE SENSORS SHOULD ASSURE THAT THE ABOVE CORRECTIVE ACTIONS ARE IMPLEMENTED IN ORDER TO PRECLUDE SIMILAR FAILURE MODES". Naturally, our Product Quality Alerts receive widespread, across programs, distribution.

RECOMMENDED IMPROVEMENTS

Process Readiness is a management tool that has been used by General Electric's Space Division for ten years. Its purpose is to produce highly reliable flight hardware repetitively without unusual or complex quality problems which would impact cost or schedule. Just as an increase in prevention costs tends to lower failure costs, expenditures for Process Readiness tend to reduce the number of failure analyses required on a program. Process Readiness is defined as a management action which assures that process development, documentation, tooling, equipment, facilities, materials, and trained personnel are certified "ready" before use of the process for the production of flight hardware. The Process Readiness Team consists of three experienced functional managers, one each representing Quality, Manufacturing, and Engineering. The same team members service all programs to assure consistent implementation of process readiness concepts and to provide an independent unbiased examination of program requirements. During the initial phases of a new program, the Process Readiness Team interviews senior program dedicated personnel to discuss the hardware required and the proposed processes necessary to produce it. Processes that have not been previously proven, proven processes that have a significantly different application than on past programs, and existing processes currently in use requiring re-examination are candidates for a thorough readiness review. A Readiness Plan is then prepared for each identified critical process. The Plan is divided into the following five standardized factors: Process Development; Documentation; Tools, Equipment, and Facilities; Training; and Prime Tryout. The Readiness Plan utilized in this presentation was prepared for a special cable. The potting material had been used for potting on past programs and personnel had experience in pin welding. However, due to the cable configuration

and the application of these processes in this case, certain refinements to the potting and welding processes were required. Program Process Readiness meetings are usually held on a weekly basis. It is the responsibility of the Process Readiness Team to assure the completion of all action items and to demonstrate this to the satisfaction of Program, Quality Manufacturing, and Engineering Section Managers. This demonstration often includes a tour of the facility where the process is performed. The Section Managers then issue a certification addressed to the Department General Manager attesting that the process will produce reliable flight hardware repetitively without unusual or complex problems which would lead to damaged hardware, high cost, or slipped schedules.

The Defect Analysis and Trend Evaluation (D.A.T.E.) System is a new management tool being utilized by General Electric. Twenty-one different elements from each nonconformance report are entered into a computerized system in order to establish a data base which in turn determines defect history. Nine different reporting formats have been identified and of these nine, the following two reports are most utilized: sequenced by nonconformance report number and sequenced by drawing number. More than 3,500 NR's have been entered into the data base within the past year and each day, more and more people, including customers, are making use of the stored data.

ORGANIZATIONAL RESPONSIBILITIES FOR FAILURE ANALYSIS

Failure analysis should be divorced from the Program Office. Responsibility should reside in the functional organization preferably within either Quality Assurance or Reliability. It is felt that this would result in the following benefits: a more independent analysis; a dedicated team to service all programs cost effectively; and a better flow of information and "lessons-learned" across programs.

CUSTOMER'S ROLE IN FAILURE ANALYSIS

The customer should not be directly involved with each failure analysis but instead should receive copies of all published reports. Failure analysis results should be reviewed during customer/contractor meetings, e.g., Failure Review Board (FRB) and Corrective Action Board (CAB); during which time customer representatives are entitled to satisfactory answers to any questions which might arise. By far the most important role for the customer is to serve as a consultant since some customer representatives have extensive experience wich many contractors and can provide constructive guidance to a contractor who is wrestling with a "unique" problem which in reality has already been solved by another contractor.

FAILURE ANALYSIS IMPACT ON SYSTEM RELIABILITY

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The effective utilization of the Rome Air Development Center's (RADC)[1] capabilities in microelectronic device failure analysis has been instrumental in improving the reliability of military electronics. The Center, designated the Air Force's reliability focal point, maintains a Quick Reaction Failure Analysis Laboratory for direct reliability support of Air Force and DoD equipment and systems on a priority basis. Its mission is the analysis of semiconductor device failures in production and field equipment, the identification of contributing failure mechanisms, the recommendation of corrective actions and the execution of system fixes on a quick reaction basis. The technological base for the RADC failure analysis expertise is derived from in-house and contractual device reliability R&D programs, experienced technical personnel, extensive analytical facilities, an existing corporate memory and continuous involvement in diverse system support projects.

Microelectronic device failure analysis, a dynamic and vital function, provides timely solutions to DoD system part reliability problems. In resolving these device reliability problems, in-depth failure analysis is the key task leading to corrective action recommendation, implementation and evaluation. Proficiency in this area not only requires a thorough understanding of component design, materials, processing, assembly, packaging and test methods, but also a knowledge of device environmental and functional failure conditions -- important factors to be considered in defining a failure as either component or application related. This analysis expertise, however, comes at a price. Specialized analyst training, periodic facilities updating and experience are essential to make available advanced failure analysis techniques and instrumentation and employ these tools to meet the demands of today's complex semiconductor technology and assure valid analyses.

Because the overall task of the failure analyst is both technically and administratively demanding, it is important to examine this key study and its management in detail. If one were to assess the technological accomplishments in the field of microelectronics over the past fifteen years, one might conclude that the semiconductor process specialist usually held the winning hand, and that the game plan of the failure analyst was basically a catch-up strategy. The analyst has been forced not only to keep abreast of a fast moving technology with its proprietary process innovations such as device manufacturing, testing, and applications, but also to investigate new developments in failure analysis techniques and other related reliability subjects. His task often entails solving a device problem while concurrently deducing the processes employed, a reverse engineering situation. Contrasted with the engineer who designs and builds new equipment , a concrete goal, the analyst must be highly motivated to pursue a somewhat intangible objective, improved equipment reliability. To make matters worse, this expertise is usually sought late in time during equipment production or after deployment, when other attempts to correct problems have failed. This coming-on-board downstream is due in part to the time/temperature dependency of certain failure mechanisms, among other reasons. Obviously, this minimum time to react, without causing unnecessary production delays or operational down-time, adds to the pressure of effecting a fix.

The critical step for attaining improved device reliability is corrective action feedback to the part vendor. Here, the data gathered by device test and analysis, and other prior experience, is applied in devising a viable solution for rectifying the specific part problem. Corrective action, based on part test and analysis findings, may take the form of a design, material, process or test change and, occasionally, circuit application modifications. Design and fabrication changes usually pertain to the device itself. The potential reliability improvement must then be verified by further test and evaluation. A test

change, assessed on a completed product, may consist of specifying either additional parametric/functional tests or new screen tests tailored to a specific failure mechanism. It may also be necessary to recommend a device change when process incompatibilities exist or when effective screens cannot be devised, are impractical or are too expensive.

Finally, the corrective action implemented is often governed by system constraints such as cost, delivery, performance, configuration and ease of retrofit. Part availability may also be a significant factor. Each reliability fix must be assessed on an individual basis, taking into account all system requirements and corrective action alternatives.

System support priorities and device criteria must be imposed to effectively manage a failure analysis activity within an R&D organization. The criteria used by RADC for decisions on committing manpower and resources for system support is briefly outlined below.

<u>Criteria for Failure Analysis System Support</u>

<u>Customer Priorities</u>

- Air Force
  - AFSC System Product Divisions & Contractors
  - AFSC Laboratories & Test Centers
  - AFLC
- Department of Defense
- Other Government Agencies
- Industry

<u>Support Criticality</u>

- System Priority
- Device Technology Involved (Semiconductor Technology)
- Device Usage
- Critical System Components
- Reliability Data Requirements (Failure Modes/Mechanisms)

Selected criteria warrant further explanation. As indicated, semiconductor technology is emphasized. Since field failure analysis efforts usually involve yesterday's device technology, in varying degrees, and system designs, due consideration is given to the need versus benefit tradeoff. Here, current or anticipated high volume device usage is a factor assessed. Lastly, critical system components often involve one of a kind devices, small volume usage, and occasionally, non-semiconductor components, all valid points to appraise prior to system support commitment.

After accepting a system support job, there are several factors the failure analysis activity manager considers in planning and executing the effort. These factors are presented briefly below.

- Determine resources required such as manpower, travel funds, and supplies and equipments.
- Assign appropriate personnel to the technical analysis area involved.
- Establish definite schedules for analysis completion and the preparation of a technical report based on existing system schedules.
- Estimate additional time required for any follow-up actions and briefings in light of other current or anticipated system support commitments.
- Adjust job schedules periodically based on existing workload and system priorities.
- Plan workload to allow some flexibility for handling unanticipated high priority system support requests.
- Interfacing with people at all levels of authority and maintaining a positive, aggressive attitude toward assuring the reliability of military defense systems at reasonable cost, without sacrificing performance.

Where the failure analysis activity is an integral part of the system support

organization, as is the case at RADC, the analysis team is faced with demanding follow-up actions. The job doesn't end after determining the failure mode/mechanism and suggesting a fix. Effective corrective action implementation involves many other factors:

o Convincing system managers that the recommended action is necessary. This implies being prepared to defend analysis findings and recommendations at all levels of authority. Sound technical efforts can be negated by poor salesmanship.

o Relaxing defensive attitudes on the part of any one or all parties concerned. The "not invented here" hangup, or "it's the other guys fault" disposition, must be diplomatically addressed when third parties are engaged for performing analysis and recommending solutions. A positive attitude reflecting a cooperative effort in problem solving can ease tensions.

o Overcoming inertia, resistance to change, when implementing corrective action that interrupts production flow, delays delivery or increases costs. Persistence is essential throughout the corrective action transition period.

o Acting as a mediator between the responsible government agency and the vendor or contractor. Each party has a vested interest in the outcome of any action taken. Industry wants to make a good product, but must make a profit to stay in business. Government agencies have the responsibility to spend the taxpayer's money wisely without sacrificing system reliability or performance.

o Recognizing the sometimes overriding factors. Management conflicts arise because of unrealistic or absent equipment reliability specifications, existing performance/reliability tradeoffs, limited funding and proprietary data claims, to name a few.

o Overcoming contractor reluctance to admit questionable reliability practices like using non-standard/non-military specified devices to reduce cost, sole source "critical device" procurements, interdivisional subcontracting, "keep it in the family" tendencies, and designs using new devices with unproven reliability.

These cited pursuits are unavoidable for assuring that recommended corrective actions are brought to the attention of decision making authority, technically understood, and properly weighed against other system constraints. The impact of corrective action on system reliability is realized only when implementation has been accomplished and evaluated. The experienced and effective failure analysis activity manager must be aware of these concepts and continually strive to maintain the degree of system visibility needed to accomplish this formidable job.

Recognizing that the management of an effective failure analysis system support activity presents a real administrative challenge, let us now turn to the failure analysis laboratory environment and address the technical dilemma which semiconductor device technology presents to managers and analysts alike. Five main steps are blocked out from the definition of a device reliability problem to a completed system fix:

o Failure Verification

o In-Depth Failure Analysis

o Corrective Action Definition

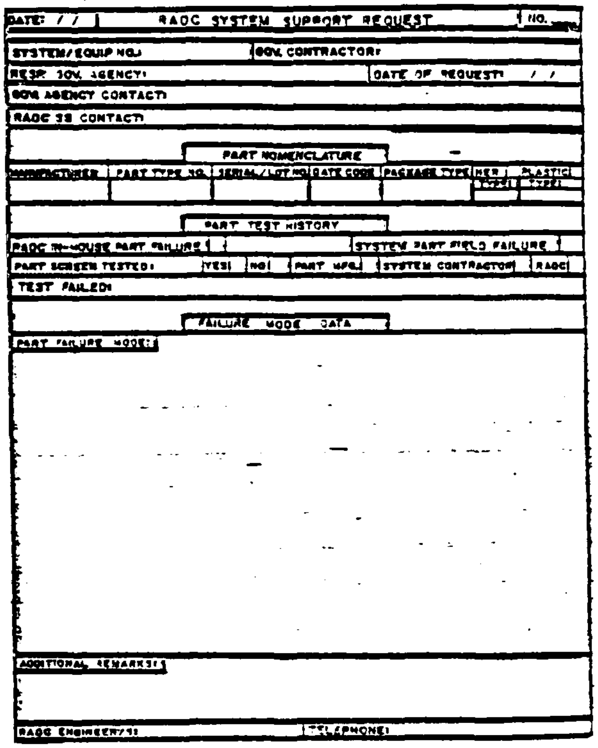
o Corrective Action Implementation

o Corrective Action Evaluation

Failure verification involves functional and environmental testing to determine whether a device is an actual failure, intermittent failure, or retest good. Field repair technicians often replace several components before correcting equipment malfunction because fault diagnostic procedures often don't isolate failure at the part level. The device may also be temperature sensitive, recovering after power or temperature conditions are removed , which requires further verification testing. Operating the device with power applied at temperature for extended periods may be necessary. Thus, classifying a suspected part failure as "retest good" often means more test time than verifying an actual failure.

During the failure verification phase, a review of device operational and failure history can aid in selecting the most appropriate tests to perform. This is accomplished by direct contact with cognizant personnel,

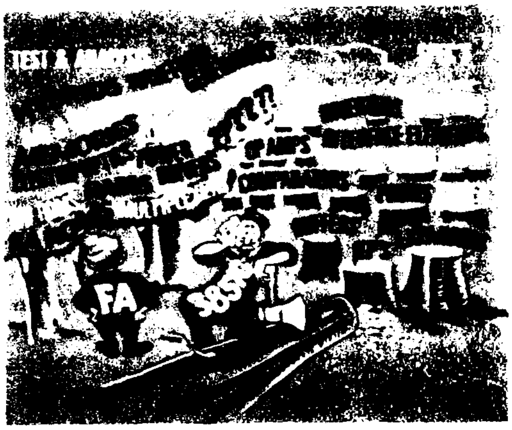
whenever possible, and by the use of the illustrated RADC System Support Request Form provided to authorized DoD requesters.


DATE: / / | RADC SYSTEM SUPPORT REQUEST | NO.
SYSTEM/EQUIP NO: | GOV. CONTRACTOR:
RESP. GOV. AGENCY: | DATE OF REQUEST: / /
GOV. AGENCY CONTACT:
RADC SS CONTACT:
PART NOMENCLATURE
MANUFACTURER | PART TYPE NO. | SERIAL/LOT NO. | DATE CODE | PACKAGE TYPE | HER. TYPE | PLASTIC TYPE
PART TEST HISTORY
RADC IN-HOUSE PART FAILURE | SYSTEM PART FIELD FAILURE
PART SCREEN TESTED: | YES | NO | PART MFG. | SYSTEM CONTRACTOR | RADC
TEST FAILED:
FAILURE MODE DATA
PART FAILURE MODE:
ADDITIONAL REMARKS:
RADC ENGINEER/S: | TELEPHONE:

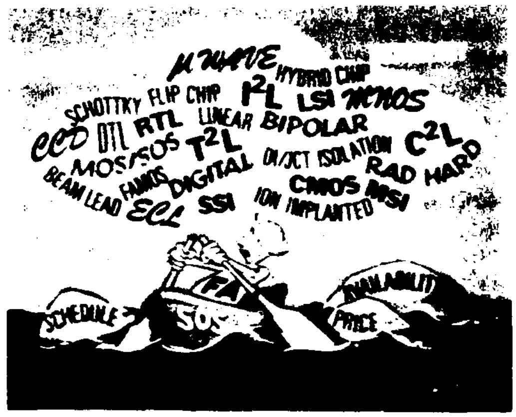
Unfortunately, device history is frequently unavailable or too limited in detail to provide useful data. Whether device failure conditions are provided or not, the analyst must always make a determination of whether the failure is a device-related problem, system design deficiency, or environmentally induced.

In-depth failure analysis attempts to identify the device failure mode and failure mechanism. Electrical failure modes are usually classified as opens, shorts, or parameter out of specification. The failure mode degree can be categorized as catastrophic, degradation, or intermittent. The failure mechanism is the basic chemical reaction or physical change associated with the device, which results in a failure mode recognizable by measurement. Similar definitions can be assigned to mechanical failure modes and mechanisms.

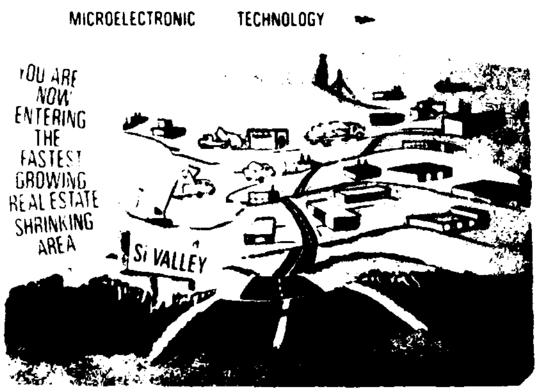
The illustrations shown convey at a glance the magnitude of the analyst's problem in dealing with rapid technology advances. Both the design engineer and system analyst have been forced to use digital rather than analog techniques for implementing most system functions. The proliferation of device functional types, particularly microcircuits, was attractive to designers from an increased performance standpoint. Understandably, new devices were designed into equipment before their reliability was fully assessed. The spec writer and the analyst tried valiantly to keep pace.



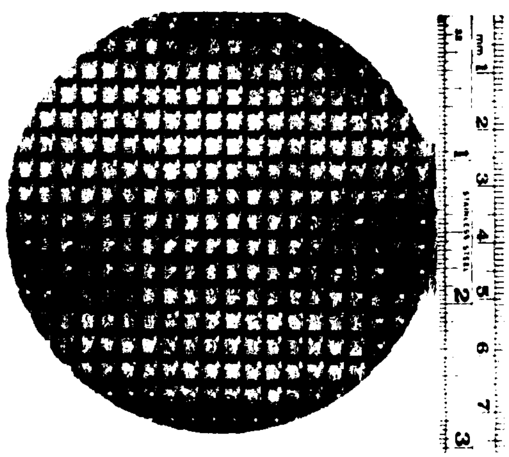
These diverse microcircuit electrical functions evolved from novel design concepts and the development of new processes. The variety of microcircuit generic types has constantly increased, each having certain advantages over other types. Examples are ECL(speed), CMOS(low power consumption), MOS(high input impedance), low power Schottky(improved speed-power product when compared to standard TTL logic). Factors like the non-volatility of MNOS memories when compared with TTL and MOS product, the improved radiation hardness of devices using dielectric isolation, and the advances in microwave solid state devices have forced the analyst to expand his focus on technology frequently. It should be apparent that the failure analyst must have a working knowledge



of many device types and their processing differences to maintain a quick reaction response in the system support environment. Staying on top requires a balanced R&D program in device technology and reliability.



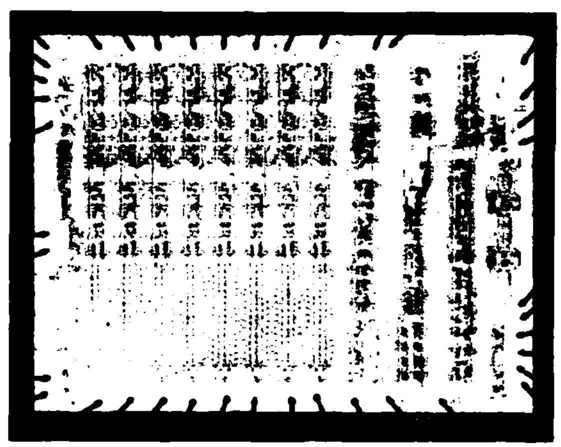
Concurrently, an even more demanding task has been the development of new and the refinement of established failure analysis techniques to meet the challenge of increasing microcircuit functional element density. The advent of the three and four inch wafer processing technology coupled with the reduction of device geometries on the chip, made possible by improved process control, has resulted in the current LSI memories, microprocessors and complex peripheral devices. These highly complex devices pose a major

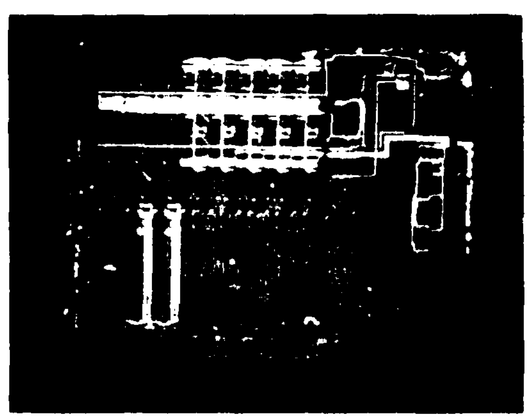


problem in failure verification, and in-depth analysis has quickly become a monumental task. Sophisticated electrical fault isolation techniques using computer test programs, compatible with existing automated test equipment (upper right photo), are needed today to isolate a degraded circuit element in

LSI devices. In the case of microprocessors (lower photos), where isolation of failure at the element level may not be feasible, other

supplemental techniques, such as nematic liquid crystal analysis,[2,3,4] which optically highlights operating circuit paths in a manner similar to digital watch displays, are being refined to provide additional fault isolation capabilities.

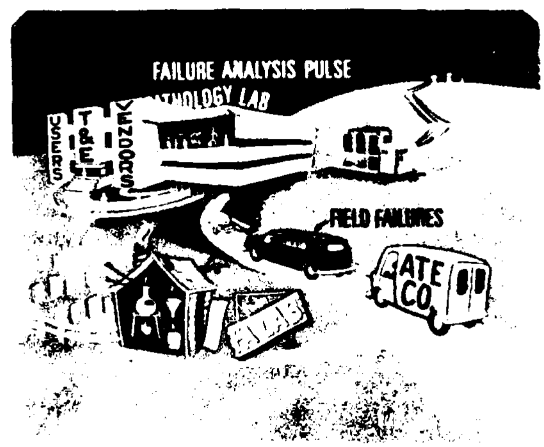




In the failure analysis area, as device complexity increased negating the use of some established techniques, selected analysis methods were further refined and new techniques were developed. Analytical tools such as photovoltage response measurements, stereo x-ray and neutron radiography, Nomarski interference contrast microscopy for surface topography enhancement, electron and ion beam instruments, mass spectrometer residual gas analyzers, infra-red thermal profilers, and other powerful analysis methods surfaced. The scanning electron microscope (upper photo) provides high magnification displays with exceptional depth of field of submicron structures beyond the resolution of optical microscopy. Another electron beam instrument, an electron probe microanalyzer (lower photo) performs x-ray spectrochemical analysis for identifying the elemental constituents of solids in a cubic micron volume.

It was also readily apparent that these powerful analysis instruments required extensive personnel training and experience,

and, in some cases, were limited in application and subject to data interpretation. These two electron beam analytical instruments, along with Auger spectroscopy for chemically analyzing material layers by depth profiling, are widely used for failure analysis of today's microelectronic devices. Thus, to successfully identify device failure mechanisms and resolve part and equipment reliability problems, the combined data obtained by employing several techniques is often necessary. The test and analysis facilities required for failure analysis of today's microelectronic devices has also demanded increasing capital investments for functional test and analytical instrumentation. The simple but effective failure analyst's diagnostic tools of yesterday must be constantly updated to meet the demands of complex LSI technology.



In an attempt to provide the failure analyst with an updated compendium of available failure analysis techniques, RADC is preparing a "Microelectronic Device Failure Analysis Procedural Guide". The contents of the "Guide" will cover both routine analysis methods and advanced techniques as presented in the following outline.

I. General Introduction

II. Reference Documents Available

III. Failure Analysis Techniques

IV. Laboratory Safety Procedures

V. Glossary of Terms

VI. Glossary of Materials

VII. Failure Analysis Technique References

The "Guide" will describe the application of analysis techniques for the detection, identification and measurement of microelectronic device failure modes and mechanisms, using typical failure analyses as examples.

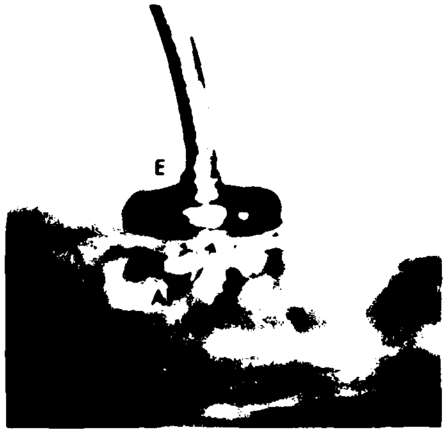
The technical talent necessary for failure mechanism studies includes personnel with backgrounds in electronics, physics, optics, chemistry and metallurgy. Having defined "failure mechanism" as a chemical reaction or physical change resulting in device failure, the analyst must then determine the many interdependent factors which can influence the observed reaction and the rate at which it proceeds. The analyst must also recognize that any one or a combination of factors such as wafer, processing, and packaging defects, time dependent reactions or changes, and environmental, externally induced, test or human error, can result in device functional failure. Each technology also has its unique problems.

The following typical case history involved corrosion of internal aluminum lead wires in hermetic package microcircuits used in an avionics computer. A typical corrosion failure is depicted in the following photo.

Computer malfunction was traced to these microcircuits which exhibited open internal lead wires. The failures occurred three years after computer installation in operational aircraft and continued to exhibit an excessive failure rate thereafter. Background information gathered indicated that a non-standard dye penetrant hermeticity test was performed. This additional leak test was felt necessary because of previously documented hermeticity test escapes. Failure analysis revealed that excessive moisture was trapped in the package cavity due to inadequate prefiring of the lid seal glass and that the dye penetrant fluid used contained significant amounts of chlorine impurity. Further analysis verified that long term anodic corrosion of the aluminum wires, as evidenced by the presence of a hydrated form of aluminum oxide at the wire break site, was caused by the chemical reaction of chlorine ions with the aluminum wire in the presence of excess water vapor. The reaction rate was found to depend on package moisture levels, chlorine concentrations, ambient temperatures and environmental vibration conditions.

Although the actual part failure analysis was straightforward, the total problem magnitude and solution was obtained by meticulous attention to details. This meant getting an accurate part failure history from the system prime and equipment contractors, reviewing the part vendors processing and screening data and even inspecting suspect microcircuits from failed computers at the flight line repair facility as they occurred. Finally, a substantial corrective action program was pursued until a successful computer fix was made.

Military munition fuze manufacturers often elected to use plastic transistors and microcircuits because of their superior mechanical properties in severe high-G drop shock and vibration environments. The cost advantage of these devices has also been quoted as an economic factor supporting their use for this application. Thus, the joint AF/contractor decision to procure large quantities of plastic devices for most fuze designs during the Southeast Asia conflict was considered cost effective with improved performance in the operational environment. This action appeared justifiable when fuze production was geared to immediate use with ordnance, but stockpiling these fuzes for indefinite periods after the SEA conflict created other problems. The known long term reliability problems associated with injection molded plastic encapsulated devices, namely, moisture penetration under high humidity storage and fractured/lifted internal wire bonds under temperature cycling conditions were underestimated. Chip metallization corrosion and open lead wire failures were the penalty. The absence of a metallurgical bond at the plastic material/lead frame interface and the thermal mismatch (differential expansion) between the internal fly wires and surrounding plastic material are the root of the reliability problems associated with these devices. Temperature cycling generated lead wire failures as illustrated in the photo below are also accelerated by out of control bonding operations (high bonding pressure) resulting in excessive bond squashout and lifting (upper right photo). These cited reliability problems, though reduced by improved materials and processes, still exist in today's plastic devices. Stored munition fuzes, periodically sampled for functionality, have exhibited high failure rates traced by in-depth analysis to the failure

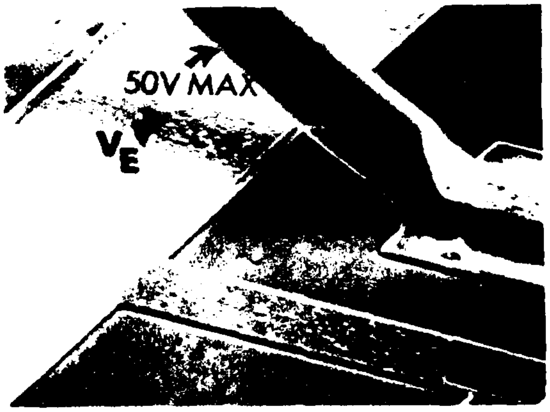


mechanisms described. Therefore, based on existing field data, the current 10-20 year fuze storage requirement demands the use of hermetic devices specified for military applications. RADC's continued reliability assessment of plastic device technology and sustained support efforts to assure the use of mil-spec devices in current munition and fuze production, wherever possible, are directed toward preventing a reoccurrence of past reliability problems. For example, the Laser Guided Bomb (LGB) initial production units employed plastic devices with resulting poor demonstrated reliability. Current production units use a high percentage of hermetic mil-spec devices, a positive action toward upgrading the reliability of an expensive but effective tactical weapon.

Equipment device reliability problems are more tolerable in ground and airborne environment applications since failures can eventually be repaired even though these systems may be operated for some intermediate period in a reduced capacity mode. In space and missile system applications, however, on-board device failures present a more critical problem. Depending on the degree of built-in redundancy with its inherent size-weight vs. reliability tradeoff, device failures can result in total mission failure at a substantial cost. Thus, "design for reliability" principles and the use of established reliability devices are essential system procurement practices.

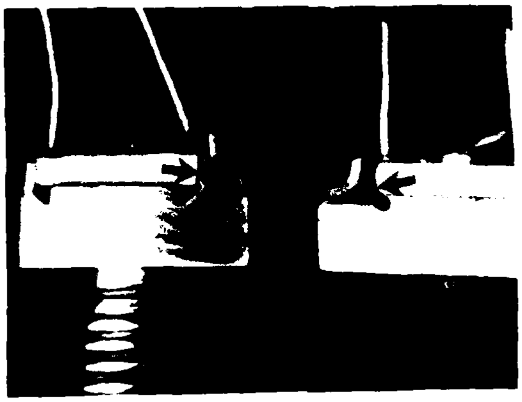
In addition to those device failure modes common to any application, another failure cause encountered in space/missile applications involves unattached particles within device packages that are free to move

randomly in zero-G environments and under the influence of electrostatic forces within the device package. Depending on their physical size, these particles can damage internal lead wires and chip passivation upon contact and, if conductive, can result in electrical shorts when lodged between lead wires and non-passivated chip metallization as illustrated in the following photos. In this



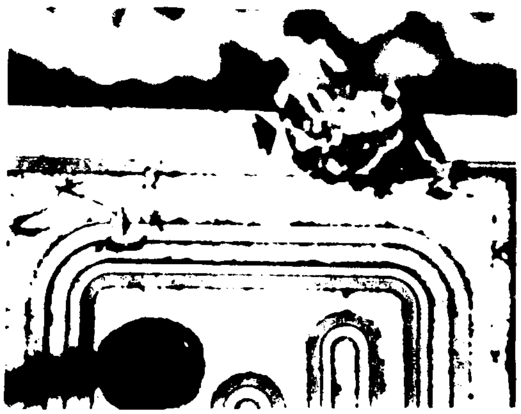
case, several microcircuit failures due to minute lid seal solder particles were detected during prelaunch system checkout testing. After assessing the reliability risk and all possible alternatives for corrective action *commensurate with existing satellite launch* schedules, a decision was made to launch without activating payload electronics until orbit was achieved. This procedure minimized possible catastrophic satellite electronics failure caused by freeing loosely attached conductive particles under launch vibration conditions, which, with power applied, could result in hard circuit shorts and lead to further secondary device failures. Follow-up device corrective actions were implemented to increase the fly wire angle with respect to the chip surface and provide adequate passivation over the chip large area peripheral metallization. Here, a single source for the microcircuit added to the time for effecting a total equipment fix prior to future scheduled launches.

Another similar event involved conductive particles in a power transistor package due to metal cover weld splash in the absence of a protective internal barrier. Depicted below are packages with and without this internal barrier for comparison (upper photo) and a typical weld splash (lower photo). The



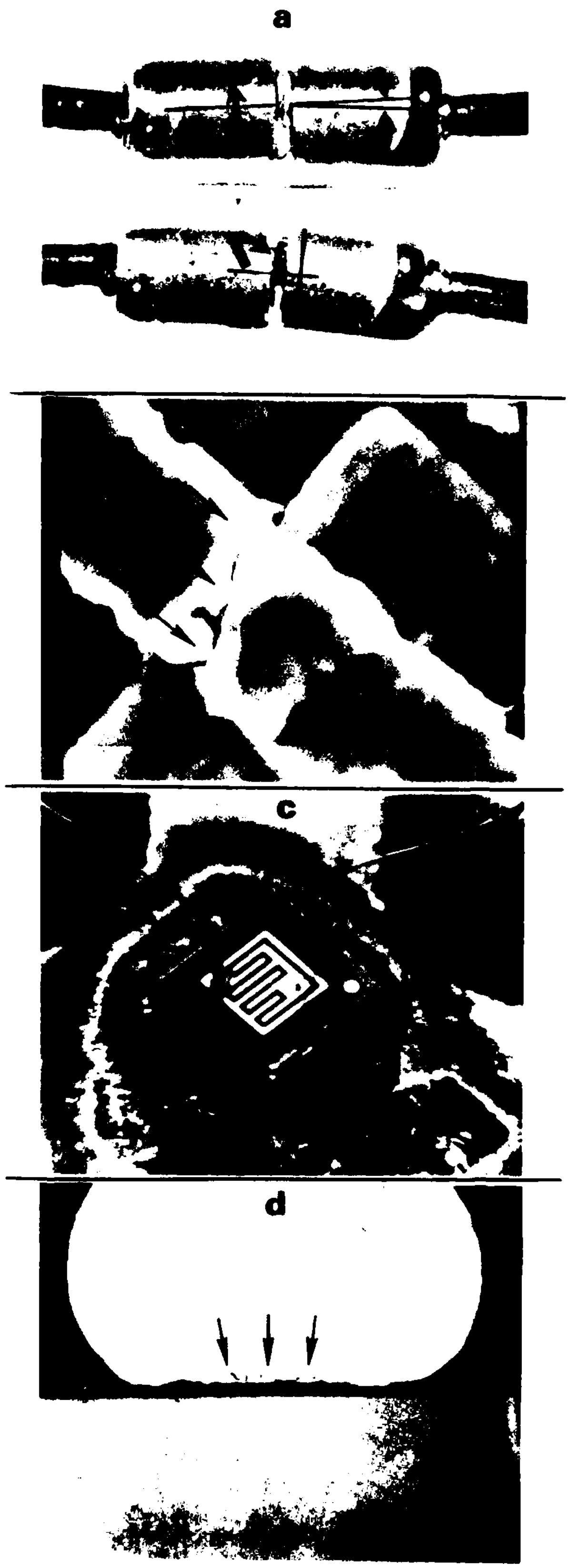
contractor overlooked published Government-Industry Data Exchange Program (GIDEP) Alerts identifying this problem associated with several transistor vendors and subsequently failed to remove devices in equipment prior to launch. Failure of the guidance system caused the loss of a \$50M Titan III launch vehicle with payload. After isolating guidance system failure to these defective transistors, the contractor issued a purge stock order and an equipment retrofit corrective action for transistor substitution.

The source of foreign material can be package constituent particles, (e.g., the nickel flake shown in the following photo which



shorted a transistor under vibration conditions), pieces of cleaved silicon from the chip itself, wire fragments, portions of eutectic chip attach (balling and flaking) and other external origin material introduced during processing and/or packaging. Their presence is attributed to the lack of process control and inadequate quality assurance screening inspections. Today, additional 100% reliability screen tests, including x-ray and particle impact noise detection, are specified for "Class S" devices used in space applications.

Other examples of device failures experienced in military equipment applications include (1) intermittent diodes (cracked pellets) due to stress caused by an off-centered pellet or axial lead misalignment during assembly (Photo a), (2) electrical opens in microcircuit aluminum metallization films caused by electromigration effects at high current densities (Photo b), (3) transistor internal wire bond lift failures due to minimal reacted bond area (Photo c), and (4) hybrid device wire bond degradation and corresponding low bond strength caused by diffusion couple voids accompanying the Kirkendall effect (Photo d). These devices were incorporated in an avionics flight control computer, ground radar signal processor, missile guidance system and space reentry vehicle electronics respectively, and required extensive analyses and corrective actions in providing quick reaction equipment fixes.

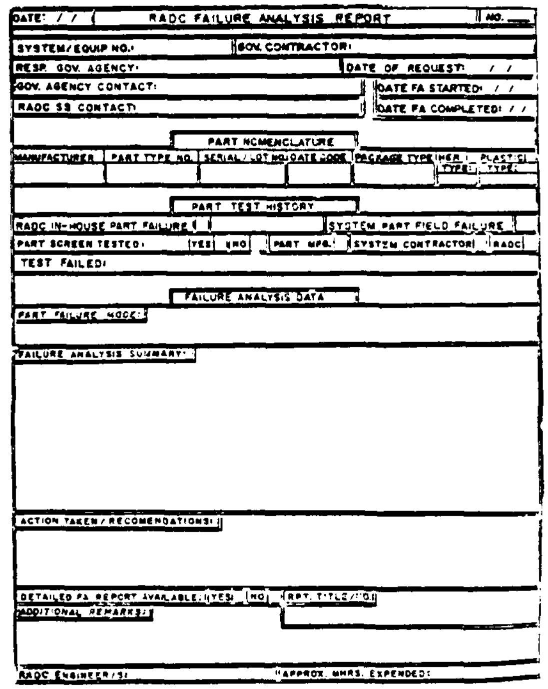


These case studies involved simple transistor and TTL microcircuit structures where sophisticated fault isolation diagnostics were not required. Analysis of today's complex devices, however, requires developing computerized electrical test vector fault routines for failure verification and isolation. Thus, the test and analysis time is rapidly becoming a larger percentage of the total manhours expended in providing quick reaction equipment fixes. If we fail to provide timely analysis on today's complex circuits, the feedback loop to the manufacturer will be temporarily opened and necessary corrective actions delayed. The system user's alternative, to maintain a readiness posture, may be a direct replacement, on an as-failed basis, of parts from the same vendor or another vendor's "equivalent" part. Extensive spares inventory and repair actions are expensive when field failures are involved. Obviously, the system designer's alternative is to use reliability proven device technologies.

The failure modes and mechanisms in current technology devices are not necessarily new, just harder to detect, isolate and analyze. Some new problem areas have surfaced with multi-level metal/dielectric structures, in chip protective networks, and soft failures including alpha particle effects in memory devices among others, which can only be solved by aggressive R&D programs.

Updating one's knowledge of factors contributing to part failure requires substantial homework, experience, and a good corporate memory. The latter involves adequate documentation of analysis findings when working in the system support environment. RADC uses both a short form as shown in the "RADC Failure Analysis Report," in addition to detailed reports which are published in periodic "RADC In-Depth Failure Analysis Quick Reaction (QR) Reliability System Support Accomplishments" reports[5] available to DoD agencies.

In planning for the future, RADC continuously updates its facilities to meet the anticipated analytical demands of tomorrow's microelectronic technology. The Center also maintains a Cooperative Education Program with several engineering universities, providing RADC a potential source of personnel with the latest engineering technology. Those assigned in the device reliability area are trained on the job in the disciplines of reliability, semiconductor technology, testing, failure analysis and system support activities.


DATE: / / RADC FAILURE ANALYSIS REPORT NO. ___
SYSTEM/EQUIP NO.: GOV. CONTRACTOR:
RESP. GOV. AGENCY: DATE OF REQUEST: / /
GOV. AGENCY CONTACT: DATE FA STARTED: / /
RADC SS CONTACT: DATE FA COMPLETED: / /
PART NOMENCLATURE
MANUFACTURER | PART TYPE NO. | SERIAL/LOT NO. | DATE CODE | PACKAGE TYPE | HER. TYPE: | PLASTIC TYPE:
PART TEST HISTORY
RADC IN-HOUSE PART FAILURE | SYSTEM PART FIELD FAILURE
PART SCREEN TESTED: YES | NO | PART MFG. | SYSTEM CONTRACTOR | RADC
TEST FAILED:
FAILURE ANALYSIS DATA
PART FAILURE MODE:
FAILURE ANALYSIS SUMMARY:
ACTION TAKEN/RECOMENDATIONS:
DETAILED FA REPORT AVAILABLE: YES | NO | RPT. TITLE/NO.
ADDITIONAL REMARKS:
RADC ENGINEER/S: APPROX. MHRS. EXPENDED:

The impact of RADC's failure analysis system support activity has been realized by the improved reliability of Air Force systems. These accomplishments range from short term equipment fixes to long term life cycle cost benefits. The time element for effecting a system fix can range from a few days, weeks or months, to more extended tasks spanning several years. The ASD RIVET GYRO Program which sought the improvement of the field reliability of operational avionics equipment, and the current Missile-X (MX) Program are typical examples of long term RADC reliability support.

Through a sustained cooperative effort with the equipment contractor, RADC accomplished a two order-of-magnitude increase in the MTBF of the F-4 Integrated Display System (IDS) by design and component corrective action implementation. Recent RADC efforts in support of the SRAM Master Computer have resulted in a net cost avoidance of $10M through in-depth microcircuit failure mechanism identification and replacement spares acquisition actions. Other ASD avionics equipments, ESD ground

systems, and SAMSO (now two separate organizations designated SD and BMO) missile and satellite programs have been successfully supported, as have many ADTC munition programs. The system support activities described also provide timely guidance in formulating the Center's reliability R&D program and pertinent data for updating military device reliability specifications and standards.

Contractually, RADC investigated microcircuit failures from production and field F-15 Head-Up Displays (HUD) and Interference Blanker Sets (IBS)[6]. This effort was

undertaken to access the reliability of current microcircuit technology in the avionics environment and the validity and effectiveness of presently used techniques for microcircuit procurement, screening quality assurance, and reliability prediction. The findings verified a 3:1 demonstrated failure rate improvement of MIL-M-38510 microcircuits over vendor MIL-STD-883 equivalent devices, thus validating the effectiveness of current microcircuit procurement documents.

The high percentage of system device field failures due to electrical overstress prompted a recently completed RADC[7] contractual effort with BDM Corporation directed toward developing a microcircuit "Electrical Overstress Tolerance Qualification Test". The "Electrostatic Discharge Sensitivity Test, Method 30XX," is currently in government/industry coordination for inclusion in Method 5005 of MIL-STD-883B and MIL-M-38510.

The overall impact of RADC's system support activities through in-depth device failure analysis has been far-reaching. Besides providing timely system fixes and guidance to the Center's Reliability Technology R&D program, the device problems surfaced, analyzed and resolved have resulted in significant inputs to military device specifications and standards, namely, MIL-M-38510, "General Specifications for Microcircuits" and MIL-STD-883, "Test Methods and Procedures for Microelectronics".

The current contractual and in-house program for compiling, editing and publishing an "RADC Microelectronic Failure Analysis Procedural Guide" will provide government and industrial organizations with up-to-date, comprehensive techniques useful for personnel training while improving the experienced analyst's knowledge and means of implementing new techniques such as Scanning Acoustic Microscopy and Nematic Liquid Crystal Displays for fault isolation diagnostics in complex LSI technology.

The improvement of microelectronic device reliability and the attainment of reliable military electronic systems depends on the continued visibility afforded by sustained involvement in system support microelectronic device failure analysis activities. It is RADC's goal to stay at the forefront of solid state technology and its system applications in this important reliability area.

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[7]F30602-76-C-0308, "Specifications For Microcircuit Electrical Overstress Tolerance", BDM Corporation, RADC-TR-78-28, March 1978, AD No. A052814

PRESENTATION MATERIAL

SYSTEM ACQUISITION RELIABILITY SUPPORT

DEVELOPMENT:

- o R&M REQUIREMENTS (PREDICTION/TEST)
- o PARTS SELECTION (PARTS REVIEW BOARD MEMBER)
- o PRODUCT EVALUATION ACTIVITIES

PRODUCTION/TEST:

- o FAILURE ANALYSIS SUPPORT
- o CORRECTIVE ACTION --
  - o RECOMMENDATION
  - o MONITORED IMPLEMENTATION
  - o EVALUATION
- o RELIABILITY ASSESSMENT OF MICROCIRCUIT FAILURES IN AVIONIC SYSTEMS (RAMFAS)

FIELD OPERATION:

- o QUICK REACTION FAILURE ANALYSIS SUPPORT
- o CORRECTIVE ACTIONS
- o LOGISTICS SUPPORT

FAILURE ANALYSIS SYSTEM SUPPORT INVOLVEMENT BENEFITS

- o SOLVE PART RELIABILITY PROBLEMS AND PROVIDE TIMELY SYSTEM FIXES
- o TRANSFER OF DEVICE RELIABILITY TECHNOLOGY TO SYSTEMS
- o GAIN VISIBILITY INTO CURRENT SYSTEM DESIGNS AND DEVICE TECHNOLOGY USED
- o PROVIDE INPUTS TO R&D TECHNOLOGY BASE PROGRAMS

FAILURE ANALYSIS' DILEMMA

THE ANALYST MUST MAINTAIN KNOWLEDGE OF:

- o SEMICONDUCTOR DEVICE PROCESSING AND PACKAGING TECHNOLOGIES
- o DEVICE GENERIC AND FUNCTIONAL TYPES
- o R & QA TEST METHODS AND PROCEDURES
- o ELECTRICAL TEST & RELIABILITY TEST TECHNIQUES
- o DEVICE FAILURE MODES/MECHANISMS

WHILE CONCURRENTLY:

- o PERFORMING IN-DEPTH DEVICE FAILURE ANALYSIS
- o DEVELOPING IMPROVED FAILURE ANALYSIS TECHNIQUES
- o UPDATING LABORATORY ANALYTICAL FACILITIES
- o TRAINING PERSONNEL

DEVICE VS DESIGN RELIABILITY PROBLEM

- o DEVICE RELATED PROBLEMS
  - (1) PROCESSING & PACKAGING FAULTS
  - (2) ELECTRICAL TEST DEFICIENCIES
  - (3) RELIABILITY SCREEN TEST ESCAPES
  - (4) DEVICE INTERCHANGEABILITY
- o DESIGN RELATED PROBLEMS
  - (1) DEVICE MISAPPLICATION
  - (2) ELECTRICAL TRANSIENTS
  - (3) ENVIRONMENTAL FACTORS
  - (4) DESIGN TOLERANCE FACTORS

PRODUCT RELIABILITY SURVEILLANCE

- o PRODUCT EVALUATION/DEVICE ANALYSIS

  A DESIGN RISK ASSESSMENT OF ALL PART FABRICATION PROCESSES.

- o MIL-M-38510/XXX DEVICE AUDITS (DESC)

  A CONTINUOUS RELIABILITY MONITORING OF MIL SPEC MICROCIRCUITS (MIL-STD-883)

- o EQUIPMENT PRODUCTION/TEST DEVICE FAILURE ANALYSIS

  EARLY DETECTION, ANALYSIS AND CORRECTION OF DEVICE RELIABILITY PROBLEMS (ALERTS)

- o SYSTEM DEVICE FIELD FAILURE ANALYSIS

  IDENTIFICATION OF TIME/TEMPERATURE/VOLTAGE DEPENDENT DEVICE FAILURES (ALERTS)

RELIABILITY TECHNOLOGY TRANSFER

ARTICLES:
- o "MILITARY MICROCIRCUITS - FAILURE ANALYSIS AT RADC" (MILITARY ELECTRONICS - COUNTERMEASURES)
- o "ANALYZING AND CORRECTING SYSTEM MICROELECTRONIC FAILURES" (DEFENSE MANAGEMENT JOURNAL)

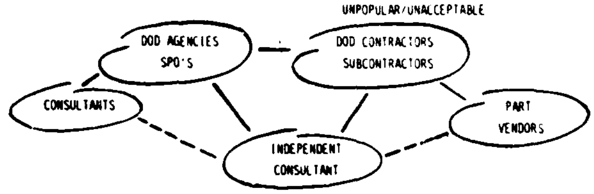
TECHNICAL REPORTS:
- o "RADC IN-DEPTH FAILURE ANALYSIS QUICK REACTION RELIABILITY SYSTEM SUPPORT ACCOMPLISHMENTS" REPORTS
- o RADC PRODUCT EVALUATION REPORTS
- o GIDEP ALERTS

DOCUMENTS:
- o MILITARY STANDARDS (MIL-HDBK-217, MIL-M-38510, MIL-STD-883, ETC.)
- o RELIABILITY DESIGN HANDBOOK
- o MICROCIRCUIT MANUFACTURING CONTROL HANDBOOK
- o MICROELECTRONICS FAILURE ANALYSIS TECHNIQUES PROCEDURAL GUIDE

SYMPOSIA:
- o ISTFA, IRPS, ISHM, R&M, GOMAC
- o AFSC R&M INFORMATION EXCHANGE MEETING
- o MISSION ASSURANCE CONFERENCE

RELIABILITY SYSTEM SUPPORT PROBLEM AREAS

- o PART SELECTION AND RELIABILITY SURVEILLANCE - PERFORMANCE (ADVANCED TECHNOLOGY) VS. RELIABILITY TRADE-OFF DECISIONS
- o SYSTEM SPECIFIED FAILURE ANALYSIS REQUIREMENTS - SOME CONTRACTOR/VENDOR FAILURE ANALYSIS EFFORTS ARE INADEQUATE/INCONCLUSIVE
- o INDEPENDENT 3RD PARTY CONSULTANT - TECHNICALLY VALID ANALYSIS DETERMINATIONS ARE OFTEN UNPOPULAR/UNACCEPTABLE



"THREE'S A CROWD"

MANAGEMENT OF EFFECTIVE PART RELIABILITY PROBLEM SOLVING EFFORTS

- o ASSESS CONTRACTORS' FAILURE ANALYSIS CAPABILITIES (INTERNAL VS EXTERNAL ANALYSIS SERVICES)
- o DEFINE FAILURE ANALYSIS ORGANIZATION RESPONSIBILITY - (R&QA ACTIVITY)
- o ESTABLISH PART FAILURE/FAILURE ANALYSIS REPORTING PROCEDURES
- o DEVELOP COOPERATIVE ATTITUDES BETWEEN GOVERNMENT AGENCY/INDUSTRY REPRESENTATIVES
- o EMPHASIZE RESOLVING PROBLEMS RATHER THAN FIXING BLAME
- o MAINTAIN CUSTOMER AN INTEGRAL PART OF FAILURE ANALYSIS TEAM EFFORTS
- o STRESS EARLY IDENTIFICATION AND ANALYSIS OF DEVICE RELIABILITY PROBLEMS EXPERIENCED DURING SYSTEM DEVELOPMENT, PRODUCTION & TESTING
- o MONITOR CORRECTIVE ACTION IMPLEMENTATION AND EVALUATION

FAILURE ANALYSIS IN THE DESIGN PHASE OF A HI-REL AEROSPACE SYSTEM - AS VIEWED BY A CUSTOMER CONSULTANT

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Systems Effective
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SUMMARY:

Failure analysis is a most important concept for mission assurance. In-depth failure analysis identifying the mode of failure and the exact mechanism which produced the failure (i.e, physics of failure) provide program management and the customer with the major element in risk assessment. Failure analysis means different things to different people, and therefore a definition seems appropriate. Failure analysis in the general sense, and as applied through various contract specifications, means the determination of which factor produced a malfunction and what corrective action must be taken to eliminate the potential for subsequent failures.

Applying this definition, it does not suffice to say that an intermittent "glitch" occurred, without identifying, if at all possible, exactly what caused the glitch; e.g., test equipment, operator error, etc. Identifying the cause must be validated by duplicating the intermittent "glitch" condition, if possible, and the corrective action must go beyond "employee warned." Another example: if analysis at the component test level indicates an open condition traced to an integrated circuit (IC), the IC must be failure analyzed to identify where the open condition occurred, e.g., a broken wire, a lifted bond, an open in the interconnect metallization on the device at an oxide step. Having identified the point of failure to this level, the mechanism which produced the failure must be identified, i.e., the physics of failure.

Not until the exact cause of failure is known can a valid decision be made regarding the failure at the component level test. Defining the physics of failure is also required to assess whether a piece part has a generic deficiency which could cause other similar parts to fail, <u>or</u> whether a design deficiency exists which requires redesign to eliminate the possibility of future failures.

What is important about failure analysis is that the results must provide the necessary information to take corrective action which provides mission assurance. The depth of failure analysis and the timely implementation of the various technologies required to conduct it are mandatory for valid, objective management decisions which assure the high reliability required for aerospace systems.

FAILURE ANALYSIS AT THE 1978 MISSION ASSURANCE CONFERENCE

In preparation for this presentation, a review of the 1978 Conference Proceedings was appropriate. As a part of this review, it was noted that the keynote speakers' presentations in the first fourteen pages made several references to the impact of mission failures, the need to know what causes failures, and that the aerospace industry had a "ways to go" relative to the isolation of failure causes to be able to assess risks.

o <u>Major General Howard E. McCormick - Vice Commander SAMSO</u>

". . . The impact of a small number of failures can be devastating.

". . . Loss of operational capability . . . and loss of resources."

". . . Impedes our ability to obtain congressional support . . ."

o <u>Dr. John W. Townsend, Jr., President, Fairchild Space and Electronics Co.</u>

"His (Lt. Gen. T. W. Morgan) challenge was to identify and suggest solutions to general problems that had resulted in or contributed to space mission failures."

o <u>Walter O. Lowrie, Vice-President, MX Program, Martin Marietta</u>

"Cause of failure, personnel error . . . is a trap because it is a garbage can for hiding all sorts of other things."

". . . treat all failures with the same rigor as if it was a flight failure." ". . . as an industry, still have a long ways to do better in this concept of cause isolation from the system level clear down to the parts level into the physics of failure."

". . . know where the risks specifically were." ". . . somebody at the top level of the project personally assesses the risk and buys off the risk."

In the remaining three-hundred pages of the proceedings, there was virtually no reference to the importance of in-depth failure analysis as a management tool for mission assurance. This criticism is aimed at program/project management who were the presenters at the 1978 Conference. Below are some of the concepts abstracted from these presentations.

o We all inherently want a success - it's human nature

o Our company must have a good reputation - new business

o Our management provides in depth, timely review of all program aspects

o We use a complex program audit system to assure program success

o We have numerous, effective program reviews

o Using independent readiness review teams helps, but we need more, sooner

o We want our incentive monies, so we must do a good job

<u>FAILURE ANALYSIS IN THE 1980 MISSION ASSURANCE CONFERENCE</u>

It is obvious that the planners of the 1980 Conference recognized the need for discussions concerning failure analysis, and elected that such interchange be emphasized relative to the design phase of an aerospace program. The comments presented here relate to a high-reliability program where the design is under full configuration control and qualification and/or demonstration system are being produced for delivery. Whether the program is to produce a commercial or government high reliability spacecraft is not germane, the comments apply equally.

To promote the desired interchange, speakers from two government contractors and two government support/consulting organization were invited to participate. The chair of this session structured a series of questions that each panel member was to address. To understand this writer's point of view, the following information is offered.

Since the early sixties, assignments at two major aerospace companies have involved mostly "fire fighting" after

failures have occurred at all levels of design and testing. No matter how much time, effort and money were expended oversights occurred which contributed to malfunction. In general the aerospace industry has numerous exemplary successes, but we have those few failures that have such a dramatic impact that success is often overshadowed.

With the definition of design phase and the admission of being a self proclaimed pessimist, the following comments are offered in response to the specific questions of our session chairman.

WHY FAILURE ANALYSIS IN THE DESIGN PHASE?

Most of the reasons for in-depth failure analysis in the early stages of a program are obvious:

o Identify "weak-links" in the early stage of the program so corrective action has a maximum reliability and minimal schedule impact

o Eliminate the use of less than optimized parts, material or processes

o Circumvent delays and cost to the program caused by failures at various levels of assembly and integration

o Ambiguous system/ component performance during the testing phase to "hard" reality so valid engineering and management decisions can be made

o Establish a program baseline for failure causes so trend analysis is meaningful and possible

o Establish basis for critical item control if use of specific parts, material or processes is mandatory for fabrication of the system, and is prone to possible failure

Considering the above, it is extremely important to have an understanding between the contractor and customer to what depth the failure analysis is to be conducted and just how the results will be applied to the program to accomplish the desired mission assurance goals. There is little doubt that the contractors commitment must be tempered with a "cost effective" factor; however, the in-depth analysis is a prerequisite to the determination of what is cost effective.

RECOMMENDATION:

Considering the question, it seems obvious that the customer should define requirements explicitly in the RFP, and that each potential contractor should respond in an explicit manner so that an objective comparison can be made a detail part of source selection.

WHERE DOES THE RESPONSIBILITY FOR FAILURE ANALYSIS REST IN A PROJECT OFFICE?

It is virtually impossible to provide a general answer to this question for all types of contracts; each contract must exercise options to place the responsibility in an independent, objective quality related function, but must also assure that project office obligations and responsibilities are met. Each contractor's functional management should establish by policy/procedure the requirement for the quality function to be responsible so program/project shortcuts in failure analysis are not allowed to occur. With these considerations in mind, the following concept is offered:

o The responsibility must be shared between the program manager and the quality assurance (Reliability/System Effectiveness) manager

o The customer must be notified of all failures at all levels.

o The depth of analysis must be defined by QA with program office understanding.

o The customer must concur with depth of analysis defined.

o The program and QA manager must evaluate failure analysis results and concur with recommended corrective action.

o The failure must be closed out through the Failure Review Board with customer right of disapproval.

o Corrective actions must be implemented through Corrective Action Board with customer concurrence.

The above concept assumes that the "human equation factors" of team effort are realizable and that adequate personnel, facilities and funding are available; wonderful assumptions that are difficult to attain, but which must be pursued with maximum vigor.

RECOMMENDATION:

After failure, an objective quality organization should have primary responsibility to determine the level of analysis to be conducted and should define the corrective actions to be implemented. A major consideration would be the company's policy, established by company functional management, that assures that program/project management does not overpower the quality organizations charter to control failure analysis activities.

The customer should provide technical assistance and reserve the right of disapproval.

WHAT IS THE VALUE OF FAILURE ANALYSIS TO PROGRAM SUCCESS AND SCHEDULE?

This question is very difficult to answer, it depends where you are "coming from". Failure prone materials and parts which are not detected early in the program, essentially guarantee that the program will not meet cost, performance and schedule objectives. The failures will happen. From the writers view:

o Each failure is indicative of a potential schedule problem and/or mission failure

o Early failures will allow for redesign, reselection of parts, application of enhanced screening and testing, or other practical corrective actions

o Comprehensive in-depth failure analysis allows for objective risk assessment and program management/customer decisions.

The three above factors value to a program's success can best be illustrated by examples:

o In an early ICBM program (early 1960s), a major supplier's integrated circuits (ICs) experienced numerous failures at the component level. At that time there were reportedly 50,000 ICs on the shelf at the contractors and 50,000 ICs in the "pipe-line" at the suppliers. After a comprehensive failure analysis, the time temperature mechanism was defined and an unique electrical screen developed which allowed the program to go forward using rescreened ICs.

o In an ongoing military satellite program, numerous failures were experienced with a DTL integrated circuit. Failure analysis indicated that gold ball-bonds were prone to failure for two reasons: 1) metallization was thin at the

bond pad and the package was furnace solder sealed. The combined situation was shown to have a high probability of failure, therefore, the units were retrofitted.

o In a more recent communication satellite program, a launch was delayed because two identical satellites in assembly and test had experienced several transistor failures. Detail failure analysis identified the time-temperature dependent wire bond failure mechanism and also identified that there was bond redundancy within the power transistor. Considering the fact that failures were being caught during system/component tests and the launch satellite had not experienced failure, and that redundancy within the transistor would require two failures to cause device failure, and that the satellite had redundant components, the launch was authorized and the satellite has over 3 years of successful orbital operation. Of course, all transistors in the two satellites in assembly and system test were retrofitted.

o A recent government satellite program had a continuing series of Central Processing Unit failures traced to a hybrid RAM. After extensive failure analysis by the hybrid supplier and numerous "finger-pointing" meetings between the device supplier, the hybrid producer and the system contractor, the device supplier was indicted. As a result, the supplier "cleaned up his act", the hybrid producer performed more extensive electrical screening of the RAM device before hybrid assembly and of the hybrid. The contractor performed more extensive testing at the printed wiring board and component level. The customer also established the capability to simulate on orbit malfunction in the event they occurred, and the ability to reprogram the CPU to reestablish a failed CPUs functionality.

It is hoped that these examples indicate the significance of failure analysis relative to risk assessments made early in the program, until launch, and after. In-depth failure analysis reduces these risk assessments to engineering decisions based on facts and data, rather than decisions based on "gut-feelings" and program pressures.

RECOMMENDATION:

Use failure analysis early in the program to detect and define problems so cost, performance, and schedule objectives can be met. Use in-depth failure analysis to both circumvent problems which could occur, and to expeditiously solve those which do occur.

HOW IS LASTING CORRECTIVE ACTION ASSURED?

When a failure occurs, and the necessary analysis has determined the physics which caused the malfunction, both supplier of a material or piece part, and/or the contractor are implicated. Someone inadvertently or consciously "slipped-up." The customer could also be implicated. In any case, they are all in it together so the necessary corrective actions should be determined, concurred with and implemented as expeditiously as possible.

Voluntary corrective action is a rare event when you experience it; "I made a mistake and I'll correct it," are words seldom heard. If such is the case, and the corrective action is technically and economically valid, the job is done.
But, more generally it becomes a real fight:

o We met the spec, it is not our problem that it failed.

o We conducted an extensive, objective series of tests that shows that failure was one in a million. Data you ask? Don't have that right now but - .

o Correction action? We'll take care of that if we get a follow-on contract, or additional funding.

o This is a one-shot satellite program and corrective action requirements were not in the contract.

o This part has never failed before. How many programs have used it before? I'll have to look into that.

o We make it the way we always have and if it failed, you must have done something wrong. Quality Control you say; what's that?

With this type of response, the battle lines are drawn and under these conditions the contractor, customer or government must <u>attempt</u> to force corrective action through new specifications, a new supplier, unique contracting, etc. The government often mandates it through contract requirements and specifications but again generally not without a fight. The significance is that delayed corrective actions is potentially costly in dollar, schedule and performance.

<u>COMMENT:</u>

Most corrective action is done on a case-by-case basis and it is difficult to generalize relative to the effectiveness. However since reliability and cost effectiveness are paramount, perhaps an <u>award fee</u> type of arrangement for voluntary implementation of <u>significant corrective actions</u> would be warranted, especially in the design phase. The main concern is that lessons learned are not forgotten or overlooked.

Obviously, voluntary corrective action is more timely than forced corrective action. Another consideration, numerous <u>operational failures</u> have been identified to <u>known</u> failure mechanisms, which were ignored and no corrective action taken.

<u>HOW BEST TO EXCHANGE FAILURE ANALYSIS INFORMATION?</u>

For those who have worked in the failure analysis technology field for a number of years, the best answer to this is - get on the phone and call one of your colleagues who specializes in the technical area of concern. There is no better way, because the co-workers are concurrently experiencing the same problem, or have already progressed to the point of implementing corrective action. Another thing, be sure that there is a mutual exchange, not just enough biased interchange to support your or your boss's theory. "Bounce" your information off your customer; he may have a lead. Telecon or direct interface with your fellow technologist has started many analyses off on the "right-foot" and had a very positive result in cost avoidance and timely solutions to problems. Also, don't stop with the first expert; you need a consensus, if possible. Another point, these verbal interchanges, with some degree of discretion, should never result in adverse legal action against your employer.

The other presentations in this session will detail how their companies or organizations provide for the interchange of failure analysis information, and most probably their systems are satisfactory to their customers. The real question is how effective is the system and is the intent of such a system understood.

Within a company, unless leaks occur, a supplier's product or

procedure can be "bad-mouthed" without too much concern for legal action. Therefore, you can call your shots as you see them and other programs can effectively use, if they are astute, the information to correct or circumvent problems. The real concern, especially within a large company, is getting the principals involved in the failure analysis to write the problem and solution into the system, preferably from the occurrence of failure, periodically updating and finally detailing the mechanism and corrective action. Assuming that this information is written into the systems, does each program in the company then draw from that system? Do the individuals involved in reviewing the system's information recognize "their" problems from the description provided? Does the description of the problem readily delineate generic facts that should allow a proper extension of the concern to all possible products? Physics of failure is based on the laws of nature, not on a specific materials or material combination or a lot date code, or necessarily one supplier's product. This fact must be understood and employed while using the companies failure analysis reporting system. Again, if the human factor and technical experience is present, and the system works as it should, most, if not all known failures can be minimized or totally circumvented. Some more wishful thinking -

Technical conferences are a blend between the person-to-person interface when experts meet and talk to each other, and the company systems where written technical reports are presented. Of course, the technical presentations at a conference provide a higher risk relative to legal recourse. Nonetheless, these conferences are a necessary element in the contining effort to expand the technical base for prevention of failures, or if they occur, to their solution.

It is the writer's opinion that the Government-Industry Data Exchange Program (GIDEP) Failure Alert system does not yet accomplish what is needed. Most certainly there are cases where GIDEP has served its intended function, and prevented program delays and failures. However, all too often valuable information is not inputed into GIDEP at all, or is "watered down" to the degree it is ineffective. Often there is an exceedingly long delay between a failure definition and corrective action delineation, and the input into the GIDEP Alert system. Basicly, these are related to personnel and/or legal problems.

RECOMMENDATION:

Government and industry must foster the exchange of comprehensive failure analysis information by promoting existing programs, and conceiving and implementing innovative real time concepts. Legal recourse coercion aspects must be investigated, and potential adverse liability factors minimized. Personnel involved in data exchange efforts must be trained to understand failure analysis technology and to incorporate this knowledge into the preparation of inputs. Cases where suppliers have refused to provide product as retaliation for adverse reports must also be considered, especially in the current economic conditions where commercial sales are more important than military sales.

HOW DO YOU PROFIT FROM FAILURE ANALYSIS RESULTS IN CURRENT AND FUTURE PROGRAMS?

This paper has certainly touched on this question in the previous paragraphs but perhaps a reiteration at this juncture would be beneficial:

- Properly extend the results of failure analysis to other lot date codes and generic part type and materials

- Assure that corrective actions are incorporated into program used materials and parts

- Incorporate your knowledge of potential failure causes, and lessons learned into supplier baseline, source control drawing requirements, destructive physical analysis documents, and incoming inspection/test requirements

- Let industry know the problems and solutions, and hopefully they will reciprocate

- Attend failure analysis and reliability conferences and participate in industry/government sponsored activities

- Look to the past for lessons learned to assure they have not been forgotten

RECOMMENDATION:

Assure that a closed loop review procedure which maintains a continual monitoring of failure analysis and corrective actions has been established and maintained relative to current and future program needs. Review your company's and industry's "historical files" at program inception to assure that maximized benefits are derived.

ARE CUSTOMER SPECIFICATIONS, REQUIREMENTS AND WORK STATEMENT ADEQUATE?

It is about time that we consider what may be the most limiting factor in using failure analysis technology for maximum benefit to mission assurance. The various documents in a RFP package attempt to identify to the contractor what is required for meaningful failure analysis to support mission success. In general, the contractors response is, "we will comply." At this point, there most likely is not a meeting of the mind exactly what is desired, and what the bidder has committed. Who can predict how many failures will occur; to what extent, will the analysis be necessary, (how expensive)? How large an impact will the resulting corrective actions have on the program?

RECOMMENDATION:

The following simple statements are offered as a suggested solution to this dilemma:

- The customer must explicitly define what is required in the RFP.

- The contractor must explicitly define what his perceived obligations are in response to the RFP

- Final negotiations between customer and contractor must reconcile any differences.

- The contractor must then define explicitly his obligation, and cost the failure analysis effort into his proposal. The costs should be a separate and distinct element of his proposal.

- The customer must fund at the anticipated level to assure that failure analysis requirements are met, and must be prepared to augment these funds if the customer can justify that extenuating circumstances, not under his control, have precipitated the need..

Having made these simplistic statements, accomplishing their intent then becomes a major problem. Each program must address the requirements relative to their goals. Unfortunately, available monies are generally the driving force which limits the implementation of effective failure analysis. Also consider, a contractor with several hi-rel

programs using the same materials, parts and procedures, may have a competitive advantage when a failure analyses is required, i.e. cost can be shared.

Contractor and customer must negotiate explicit failure analysis requirements and commitments for each problem, and funding must be made available to accomplish the effort.

HOW DO YOU ASSURE EFFECTIVE FMEA AND CONTROL OF SINGLE POINT FAILURES (CRITICAL ITEMS)?

This question of Failure Mode and Effects Analysis (FMEA) relative to failure analysis performance seems somewhat moot. However, the point can be made that any parts, materials or processes related to a singe-point-failure adds significance to the extent of failure analysis to be performed in the event a malfunction occurs. Conversely, if failure analysis data exists which indicates that a single-point-failure part or material has a higher probability to fail by a known mechanism than is "acceptable," redesign can be mandated, or special controls and/or screens can be implemented to reduce the possibility to an "acceptable" level. It should be emphasized that it could be very dangerous to make assumptions as to the depth of failure analysis activity relative to the consequence of failure as determined by FMEA. This type of assumption could overlook the significance of similar failure mechanisms, and restrict the latitude of redundant design.

With the above in mind, the following comments are presented:

o Each contractor shall conduct FMEA to define program imperative" single-point-failures (SPF). Program imperative implies that the system cannot be built without the SPF.

o Each designer must assume responsibility for FMEA of his design and objectively assess that a SPF is, in fact, program imperative.

o The reliability organization should verify FMEA results as early in the program as possible to validate program imperative SPF.

o All parts, materials and processes (PM&P) related to each single-point failure automatically becomes a "critical item" requiring a special attention plan defining special processing, and application requirements.

o Failure analysis and DPA of all PM&P associated with a critical item shall require a maximum level of effort (define potential or known failure mechanism, establish special screens to eliminate such mechanisms or implement validated corrective action to eliminate the mechanism).

o Use failure analysis information as a tool to more thoroughly assess the FMEA assumptions (e.g, shorted diode, open-transistor) relative to the probability of failure occurrence and the impact on system vulnerability.

RECOMMENDATION:

All RFPs, and responses to RFP should define, in detail the program requirement for FMEA, and explicit details, responsibility and procedures relative to program imperative single-point failures and critical item controls.

MISSION ASSURANCE CONFERENCE

DESIGN WORKSHOP

CONFIGURATION ITEM SPECIFICATIONS

L.A. Hartman
Lockheed, LMSC
Ernie Wade
The Aerospace Corporation

AGENDA:

In this part of the Design Workshop, Al Hartman will make a brief presentation stating why we are including configuration item specification formats and contents in a conference aimed at enhancing assurance of mission success, some background data and a number of issues to which we desire your opinion. The issues will be presented in total and we will then address each one within the group discussion period. Therefore, we request that you refrain from asking questions during the presentation. After disposing of the presented issues, any other issue with respect to preparation of specifications may be advanced for discussion. Ernie Wade will then summarize the group opinion from which the recommendations will be derived for presentation to the conference leaders.

AGENDA

• WHY CI SPECS?	
• REQUIREMENTS BACKGROUND	AL HARTMAN LMSC
• THE ISSUES	
• GROUP DISCUSSION	ALL ATTENDEES
• SUMMARY	ERNIE WADE AEROSPACE

WHY SPECS?

Configuration item specifications can and frequently do divert resources from those activities that directly support assurance of achieving mission objectives. The misapplication of resources occurs whenever excessive or gold plating requirements are included in the specification without regard to any cost benefit analysis. Confusing or ambiguous requirements always waste resources. Incomplete requirements have great potential for causing mission failure in performance, cost, or schedules. Therefore, our goal is to achieve a set of specifications that accurately reflect true mission requirements in order to ensure that resources are only expended that assure mission success.

Current practice with respect to specified requirements is that all requirements are of equal importance and, therefore, all requirements must be fulfilled. There is an order of precedence implied by the tiering within the specification tree in the event of conflict between levels of specification. However, resources can be wasted trying to achieve fulfillment of a functional requirement which would have a minor effect on achieving mission goals. The order of precedence must be clearly stated to prevent such diversion of effort.

Another diversion to assuring mission success is the tendency to spend excessive resources in the preparation and review of the specifications. A lot of these effects are hidden. Costs are hidden since not all costs show up as "Specification Preparation" costs. No one summarizes all of the design review costs as they are scattered over many unrelated organizations. Schedules reflect desires but are seldom achieved. We are each aware of the many manhours going into specification preparation and review and the failure in having approved specifications for the next phase.

Last but not least, we are examining specifications in this workshop since they are the media used for documenting primary and derived mission requirements. Such documentation has the potential for enhancing or distracting efforts leading to the achievement of a successful mission. A specification which supports mission assurance includes only needed information, clearly stated, leaving no room for guessing what is wanted.

WHY SPECS?

- FAILURE TO LIMIT REQUIREMENTS TO NEEDS RESULTING IN MISAPPLICATION OF RESOURCES
  - EXCESSIVE REQUIREMENTS
  - CONFUSING OR AMBIGUOUS REQUIREMENTS
  - INCOMPLETE REQUIREMENTS
- ORDER OF PRECEDENCE OF REQUIREMENTS IS NOT CLEARLY STATED
- EXCESSIVE PREPARATION AND REVIEW DIVERTING RESOURCES FROM FULFILLING MISSION OBJECTIVES
- SPECIFICATIONS DOCUMENT MISSION REQUIREMENTS AS RECOGNIZED & DERIVED

BACKGROUND:

The Air Force, in the first configuration management manual, defined a uniform specification program to replace the more generalized Defense Standardization Manual M200B of 1 April 1966 for application to Air Force programs. Three types of specifications were identified; Detail, Identification and Requirement Specifications. That issue of 375-1 was quickly followed by the 1964 issue which defined new types of specifications to replace the former types. They were the System General, the Contract End Item (CEI) Prime Equipment, CEI Facility, CEI Identification Item, CEI Requirements Items, Critical Components and Company Standard Parts.

At that point, the DOD suggested that a uniform approach be adopted across all components and MIL-STD-490 was the result of total DOD coordination. Thus 490 tried to cover specifications for all military items produced to contractor prepared specifications; running the full breadth from ships to rifle bullets. M200B was reissued as DOD 4120.3-M to govern MIL specifications and standards prepared by the Government or by contractors for the Government.

Since MIL-STD-490 is a compromise document representing some requirements not fully endorsed by the Air Force, MIL-STD-483 (USAF) was issued which directs certain usages of options permitted by 490 and adds additional requirements to 490. However, MIL-STD-483 is also a compromise document since all Air Force procurement is covered. Therefore, there is no specification preparation manual that is directed to the uniqueness of space programs.

BACKGROUND

- AFSCM 375-1, 1 JUNE 1962, EXHIBIT II, UNIFORM SPECIFICATION PROGRAM
- AFSCM 375-1, 1 JUNE 1964, EXHIBIT I, II, III, IV, AND V
- MIL-STD-490, 30 OCTOBER 1968, APPLICABLE TO ALL DOD COMPONENTS
- MIL-STD-483 (USAF), 31 DECEMBER 1970

ISSUES:

With that background, we workshop leaders put together some propositions in order to obtain your reaction. We have no intention of limiting the discussion period to consideration of only these issues. If any one cares to submit another proposition, use the cards provided. We do want you to wait until we have disposed of the ones I present here. We will run thru all the issues and then discuss them one at a time.

ISSUES

ISSUE 1:

The Part II, Product Specifications, are not approved until Physical Configuration Audit (PCA) which comes at the end of the development phase. They are intended to be the contractual instrument for a production phase. Since the majority of our space program procurements do not have a production phase, why not eliminate the requirement for these additional documents by including their unique material directly within the Part I specifications? PCA can be conducted as an audit against the Part I spec's fabrication and acceptance requirements.

ISSUE 1

IF THERE IS TO BE NO PRODUCTION PHASE, SHOULD PART II SPECIFICATIONS (MIL-STD-490, TYPE C) BE ELIMINATED BY DOCUMENTING FABRICATION AND ACCEPTANCE REQUIREMENTS IN THE DEVELOPMENT (PART I) SPECIFICATION?

ISSUE 2:

The first part of Issue 2 is the same as Issue 1 as applied to software specifications. There are two more distinctions between hardware and software specifications which should be addressed. Since MIL-STDs-490/483 only portray a Computer Program Configuration Item (CPCI) specification, there is a reaction that requirements at all levels with the CPCI be documented in a single specification. The question is, why not provide for lower

level specifications such as at module or routine levels? A third consideration is that current practice requires that the as-built listings be incorporated into the specification resulting in a huge document if the listings are extensive. Another problem occurs when there are two or more copies of the CPCI in use within multiple stations all of just slightly different versions, requiring multiple listings in the specification. Therefore, we propose that the listings be attached to or accompany the VDD for each copy of the program.

ISSUE 2

WHY NOT TREAT SOFTWARE SPECIFICATIONS THE SAME AS HARDWARE SPECIFICATIONS BY (1) INCLUDING CONSTRUCTION AND ACCEPTANCE REQUIREMENTS IN THE DEVELOPMENT (PART I) SPECIFICATION (WHICH ELIMINATES THE NEED FOR A PRODUCT (PART II) SPECIFICATION (REF. ISSUE 1), (2) PROVIDING FOR SPECIFICATION LEVELS SIMILAR TO PRIME ITEM, CRITICAL ITEM AND NON-COMPLEX ITEM SPECIFICATIONS AND (3) PLACING THE "AS-BUILT" LISTINGS AS AN APPENDIX TO THE VERSION DESCRIPTION DOCUMENT (VDD)?

ISSUE 3:

In addition to Issues 1 and 2, there are other reasons for including fabrication requirements in development specifications and also in system specifications. When the physical interface is now due to utilization of existing equipment, the interface should be specified in the A or B specification. A new application of existing hardware in original or modified configuration can be specified in place of specifying development requirements. Development is accomplished over time and the development specification could be used to document progress to guide further development effort. Also, the specification could document lessons learned to guide future application of the item or similar items.

ISSUE 3

WHY NOT PERMIT INCORPORATION OF BOTH FUNCTIONAL AND FABRICATION REQUIREMENTS IN TYPE A AND B SPECIFICATIONS PARTICULARLY TO

- IDENTIFY PHYSICAL INTERFACES?
- IDENTIFY NEW APPLICATIONS OF EXISTING SPACE & SUPPORT ITEMS?
- DOCUMENT THE DEVELOPMENT AS IT PROCEDES?
- DOCUMENT LESSONS LEARNED?

ISSUE 4:

After the specification has been approved to establish a configuration baseline, DOD MIL-STD-480's definition of a class I change demands that all future changes to the specification be processed as formal engineering change demands that all future changes to the specification be processed as formal engineering change proposal (ECP) submittals. Why must all changes take this route? There is a lower level of approval permitted for baseline drawing changes so why mot use it for minor changes to the specification such as the four identified on this illustration? Too often a corrective change is left undone due to the high cost of processing a formal ECP.

ISSUE 4

AFTER SPECIFICATION APPROVAL DOD-STD-480A REQUIRES SUBMISSION AND APPROVAL OF A CLASS I CHANGE PRIOR TO CHANGING THE SPECIFICATION'S CONTENT IN ANY MANNER. WHY NOT USE CLASS II CHANGES APPROVED BY THE CUSTOMER'S REPRESENTATIVE (AFPRO DCAS) FOR:

- UPDATE OF SECTION 2 APPLICABLE DOCUMENTS TO RECORD CURRENT DOCUMENT REVISIONS?
- CALLOUT OF CONTRACTOR REPLACEMENT PART NUMBERS?
- ERROR CORRECTIONS?
- ADD INFORMATION AS SUGGESTED BY ISSUES 1 AND 2?

ISSUE 5:

As lower level specifications are generated and baseline approved, the summation of the immediate lower level specification(s) contain(s) the full set of requirements from the parent documents. The parent document is in effect redundant to the lower level documents. Continued maintenance of all levels of specification will, therefore, require effort of a

redundant nature. Why not discontinue maintenance of the higher level specifications when, in effect, they have been totally replaced by the lower level set of specifications. If a major change requires additional development effort, then the higher level specifications for the modification should probably be updated or a new set of development specifications generated. Resources saved can be applied elsewhere to promote the achievement of mission assurance.

ISSUE 5

MIL-STDs 483 AND 490 IMPOSE REQUIREMENTS FOR MAINTAINING ALL SPECIFICATIONS AT ALL LEVELS THROUGHOUT THE SYSTEM'S LIFE CYCLE. WHY NOT DISCONTINUE SPECIFICATION MAINTENANCE IF THE SPECIFICATION HAS BEEN EFFECTIVELY REPLACED BY LOWER LEVEL SPECIFICATIONS?

- DISCONTINUE TYPE A MAINTENANCE WHEN ALL TYPE Bs HAVE BEEN APPROVED
- DISCONTINUE TYPE B (PART I) MAINTENANCE WHEN ITS TYPE C (PART II) HAS BEEN APPROVED

ISSUE 6:

Specifications currently permit no latitude or judgment by customer demands for the use of the word "shall" in place of "will", "should" and "may". All stated requirements have equal weight and each must be fully met. However, the real world is that some requirements directly conflict with each other or are desires which, if not fulfilled, have minimum impact upon mission achievement. Isn't there a case for including weighing factors within the specification such that attention is directed to the primary mission success factors? Paragraph 4.3.8 of MIL-STD-490 permit such goal setting for Development Specifications.

ISSUE 6

SHOULD WEIGHING FACTORS BE INCLUDED IN

SPECIFICATIONS TO GUIDE THE DESIGNER'S EFFORT?

ISSUE 7:

We have seen a trend towards the requirement for more specifications at various levels in order to "better manage" the products, i.e., control the configuration. This has several side effects: the more specifications the more redundancy in stated requirements. The more configuration items selected, the more ECPs to be written per DOD-STD-480. Effort is diverted from mission assurance to one of ensuring compatibility across documents. Why not limit specification preparation to those the contractor would do if there no CDRL requirement?

ISSUE 7

SHOULD THE QUANTITY AND LEVELS OF SPECIFICATIONS BE

LIMITED TO THOSE THE CONTRACTOR WOULD WRITE FOR

HIS OWN USE?

ISSUE 8

SHOULD THERE BE A COMPOSITE HARDWARE SOFTWARE

SPECIFICATION TYPE BELOW THE SYSTEM SEGMENT LEVEL?

IF SO, SHOULD IT ALSO BE USED FOR FIRMWARE?

ISSUE 8:

The only specification types that recognize both hardware and software components are the system/system-segment specifications. Below that level the specification types are either hardware or software. With today's rapid spread of programmed and specialized hardware/software components, should there not be a specification type that recognizes hardware/software combinations below the system level? The combined specification could also be used for firmware devices.

This concludes the presentation. Let us now go back and address each issue giving you the chance to state your opinion. Mr. Wade and I will act as monitors and watch the time to ensure some time remaining for addressing any issue you desire to present.

SUMMARY OF ISSUES AND RECOMMENDATIONS

DESIGNING FOR MISSION ASSURANCE

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Design Reviews

Issue

Industry perceives that the effectiveness of the design reviews is hindered by lack of preparedness and discipline on the part of the Government review team. The use of design reviews for tutorial sessions to educate the customer can be counter-productive to the primary objective of the design reviews.

Recommendations

- The appropriate Government program manager should insure that a small, well qualified review team is formed and briefed as to their responsibilities prior to the start of the review. Insure that the team members are familiar with the contractural requirements of MIL-STD-1521A or NASA equivalent. Insure that team members have reviewed the documentation (design analysis reports) prior to the design reviews. Insure that the Government technical experts are involved early in the contractor review process in more informal technical sessions. Consider developing a document to standardize the responsibilities of a review team for SDR's, PDR's, CDR's, etc.

2. Design Reviews

Issue

The Government perceives that the design reviews have degenerated to a public relations show to relate how "good" the contractor has performed rather than a presentation of the facts so that the review team (contractor and customer) can uncover design errors. There is no attempt to cover-up design errors but the emphasis seems to be on presenting the non-controversial rather than the areas of relative uncertainty.

Recommendations

- The contractor program manager should review the purpose of the design reviews and resist the P. R. tendency. He should realize that the uncovering of design errors is not necessarily a reflection on contractor competence. The Government should of course also recognize this.

- Format of design review sessions should include adequate time for splinter sessions where a more detailed review by a smaller group of technical experts in a specific discipline can meet and discuss problems or areas of concern on a one-on-one basis.

3. Design Reviews

Issue

Over the years the design reviews have developed into an advesary relationship between the contractor and the Government. This polarization can be detrimental to developing a truly effective approach to Mission Assurance. NASA statistics over 20 years show 65% of all avoidable errors are design errors.

Recommendations

- Build the team approach. Recognize that human beings make mistakes. The purpose of design and readiness reviews is to catch and uncover any errors. This can best be accomplished in a cooperative manner and by avoiding finger pointing and retribution. This change of attitude and approach requires implementation and support at the highest levels of the contractor and the Government.

4. Design Reviews

Issue

MIL-STD-1521A has become too general to be of real use in the space business.

Recommendations

- o Consider developing a Space Division Standard which combines 1521A and the readiness reviews required by SAMSO Reg. 550-15. This would combine and put in one reference document all the technical reviews of a particular program. It would insure reviews which are consistent with space type products. It would insure a continuity of the program from the early system requirements review to the mission readiness review.

5. Design Reviews

Issue

Government should know who the responsible individuals in various technical disciplines are and have access to them without excessive "filtering" by program offices.

Recommendations

- o Contractors should identify "principal" engineer or "cognizant" engineers in each technical discipline. Direct Government contact with these individuals should be encouraged but not overexploited so that it prevents the contractor from performing his tasks.

- o Early identification of problems and a helpful and/or assisting attitude by the Government is desired rather than a policing action. This modus operandi encourages further teamwork, understanding, and problem resolution.

6. Design Reviews

Issue

Design changes made after a major review do not always get a thorough review. These "innocent" changes are sometimes the cause of Mission failure since the subtleties of the change and its effect on other systems may not be recognized by the originating function.

Recommendations

- o All changes, both Class I & II, should be re-reviewed prior to DD-250. This can be done in a "systems review" or as a part of the DD-250 selloff process. All software changes, no matter how minor, should be reviewed by the contractor in an engineering review board and again by a Government/Contractor working group on a periodic basis.

7. Design Reviews

Issues

The use of the award fee must be carefully thought out so that design reviews are not motivated to be PR shows. If award fees are based on how well the contractor fared at a design review, the contractor will naturally promote the good and supress the bad areas. This is counter-productive to the purpose of a design review.

Recommendations

- o Separate the award fee evaluation process from the design reviews.

8. Design-Designing for the Shuttle ERA

Issue

There is a lack of timeliness and visibility of derived design requirements, including changes,

for payloads using the space transportation system.

- The development of a suitable definition of the structural loads environment is a complex task involving many assumptions. At the present time insufficient insight exists into shuttle loads methodology to justify confidence on the users part that the load definition for payloads is adequate to assure mission success.

- The impact of an unanticipated error in the loads environment definition or an unanticipated increase in predicted loads late in the program as a result of model/ methodology revisions is enormous for user programs i. e., cost increases and schedule slips in the best case. On the other hand, overly conservative approaches can severly impact mission objectives.

- Current methodology, as well as contractural/procedural shortcomings, leads to significant delays in meeting identified spacecraft needs, particularly for additional requested optional services. A specific example is shuttle dynamic model/forcing function updates to support payload load cycle calculations prior to the final preflight verification cycle.

- Because of the complexity of the problem, flight verification of the loads methodology is necessary for mission assurance on future flight articles. This requires an integrated program of data acquisition, data analysis, flight simulation and data evaluation. Limited instrumentation is currently planned for evaluation of the payload environment, and details of the required integrated effort have not yet been completely defined.

<u>Recommendations</u>

- Establish an Ad-Hoc review panel for structural loads chaired by AFSD/NASA with membership to include payload contractors.

- Review the need for similar panels for other induced environments.

- The intent in forming these Ad-Hoc review panels is to bring together involved organizations for an in depth group evaluation, reducing the need for NASA to respond to individual program requests.

  Suggested Review Panel Tasks Include:

- Perform a comprehensive review of the present basis for establishing the structural loads environment for shuttle payloads. Develop recommendations/task statements to resolve any problem areas, oversee the accomplishment of these tasks, and evaluate the results.

- Perform a comprehensive review of payload flight environment verification plans including data acquisition, data analysis, flight simulation, and data evaluation. Develop recommendations/task statements to resolve any perceived deficiencies, oversee the accomplishment of any defined tasks, and evaluate any results.

- Develop recommendations/task statements on approaches for reducing costs and improving the timeliness of such optional services as providing updated shuttle models/forcing functions to support program loads analyses. Oversee accomplishment of these tasks and evaluate any results.

- o Provide appropriate recommendations on methodology revisions, if any.

- o Provide recommendations regarding the needs for maintaining a periodic review of these areas.

- o Adequate funding for the tasks recommended by the panels needs to be provided.

9. Design-Failure Analysis

<u>Issue</u>

Effective failure analysis is a valuable tool in making critical management decisions.

<u>Recommendations</u>

- o The program manager must be appraised of potential problems and the work going on in the failure analysis of products in his program so that he has a good understanding of the technical aspects of the problem and options open for solution and correction.

- o The request for proposal (RFP) should define the requirements for failure analysis, and failure modes and effects analysis (FMEA).

- o Contractors must be explicit in what he will do on failure analysis work in response to what the customer has defined in his RFP or SOW. Final negotiations must iron-out the customer-contractor agreed-to work and tasks in failure analysis.

- o Adequate funding must be provided for failure analysis efforts; program office must be fair in their distribution of such funds or funds should come from a functional organization source.

10. Design - Failure Analysis

<u>Issues</u>

Expanded industry exchange of information on significant failure analyses and problems would save time and money and improve failure analysis effectiveness.

<u>Recommendations</u>

- o Conduct study to determine practicality of developing an industry reference source to foster such information exchange between contractors, Space Division, and NASA space activities beyond GIDEP and program-only data banks.

11. Design - Failure Analysis

<u>Issue</u>

Who should have the primary responsibility for conducting failure analysis ? The basis issue is whether or not the program office should have primary control.

<u>Recommendations</u>

- o Failure analysis should be done by an independent group (unbiased) and not in Program Office, but use team members from affected organizations. However, failure analysis must be timely and communicated to appropriate organizations. Also, if the failure analysis concerns a piece part, the manufacturer or supplier should be involved.

- o For complex failure analysis problems a team approach, including customer supplier and independent agency is desireable.

12. Design - Failure Analysis

<u>Issue</u>

There is a need for procedural guidance in conducting failure

analysis to identify various successful methods and *techniques*.

Recommendations

- The Air Force Rome Air Development Center (RADC) is developing a guidance document entitled "Failure Analysis Techniques". This document is scheduled for release during 1980. Ordering and use of this document is recommended.

13. Design/Configuration Item Specifications

Issue

Should MIL-STD-483, 490 Part II (product) specifications be required when there is no need for downstream production or second sourcing ?

Recommendations

- Provide tailoring guidance for eliminating the need to include requirements for a Part II specification in the Contract Data Requirements List (CDRL) and discourage its use for Space Division contracts whenever appropriate. Suggested method is an AFSC Policy and pamplet on use of specifications for managing a program and suggestions for tailoring to fit various kinds of programs should be issued to guide program application.

14. Design/Configuration Item Specifications

Issue

Software (computer program) Specifications are not used for purposes identical to hardware. They require that "As-Built" data be included which results in a requirements and compliance combination document

Recommendation

- AFSD should sponsor a review of software specification requirements to make compatible with hardware specification requirements.

15. Design/Configuration Item Specifications

Issue

MIL-STD-483 and 490 do not recognize inclusion of development and product specification material in the same document except as a Part I/Part II combination with each part a complete six section specification. Why not allow a combination specification with functional and fabrication requirements ?

Recommendations

- Permit updates to authenticated system and development specifications (Class I and Class II, Ref. Issue No. 4) to document development including completion of to-be-determined (TBD) items.

- Permit combination functional/fabrication specifications to incorporate usage of existing items or modification of existing items, into a new system application.

- Issue tailoring guidance instructions to incorporate above recommendations.

16. Design/Configuration Item Specifications

Issue

DOD-STD-480 permits no change to authenticated baseline specifications unless approved as a Class I change. (Ref. 4.2.1.2 a and b of DOD-STD-480 and the definitions in 110-2, 110-30 and 110-43).

Recommendations

- Issue tailoring instructions to permit tailoring DOD-STD-480A to authorize use of a Class II change to incorporate minor revisions. Such Class II changes to be approved by the customer's plant representative and furnished to the customer as an update to the CDRL delivered data item (the specification's requirement).

17. Design/Configuration Item Specifications

Issue

All specifications must be maintained throughout the program's life cycle even though effectively replaced by lower tier approved documents.

Recommendations

- Provide tailoring guidance for MIL-STD-483 which will define permissable elimination of specification maintenance requirements when lower level specifications have effectively replaced them.

18. Design/Configuration Item Specifications

Issue

Order of requirements precedence and requirements other than "shall" are seldom used even though permitted by the MIL-STD's.

Recommendations

- Promote usage of the order of requirements precedence section of the specification and use words such as "should" and "may" or establish goals as goals.

- Include in AFSD's specification preparation manuals.

19. Design/Configuration Item Specifications

Issues

Why require more specifications than the contractor requires for his own internal use ?

Recommendations

- Require justification for any requirement for specifications that the contractor would not write if not included within the CDRL as a required specification. Provide guidance strongly encouraging use of specifications normal to the contractor's system.

20. Design/Configuration Item Specifications

Issue

MIL-STD's have no provision for a composite hardware/software item below the system/system-segment level.

Recommendations

- Revise MIL-STD-480 and 483 to define development and product specifications or combinations thereof for items which contain both hardware and software components.

WORKSHOP C

SUBCONTRACT MANAGEMENT

SESSION C1 – CUSTOMER VIEWPOINT

Chairman W. R. Briggs Chief – Mfg'g Division Space Division	**Coordinator** H. N. Lange Director – QA MDAC–HB
Introduction & Overview	Mr. William R. Briggs Space Division
Subcontract Management Problems a Program Office Perspective	Col. S. O. Kennedy, Jr. Space Division
Implementation of Public Law 95-507	Col. Thomas R. Van Meter Ballistic Missile Office
Subcontract Administration	Maj. Donald R. Fowler AF Cont. Mgt. Division
The Centaur Mission Assurance Experience	Lawrence J. Ross, NASA
Overview of Space Division Part Management and Technical Requirements	Sgt. Clifford Schroeder, USAF Space Division

SESSION C2 – CONTRACTOR/SUPPLIER

Chairmen W. R. Briggs Chief – Mfg. Division Space Division	**Coordinator** H. N. Lange Director – QA MDAC--HB
C. R. Mercer Director – QA MDEC	
Overview of Agenda Problem Highlights	Mr. Charles Mercer McDonnell Douglas Electronic Co.
Flow Down of Quality Requirements to Semiconductor/ Microelectronic Suppliers – General	Mr. Conrad Zierdt Bell Labs
Public Law 95-507 Impact Upon Contractors	Mr. Sewell Kauffman McDonnell Douglas Corporation
Over the Shoulder Audit Techniques	Mr. Dave Arnott General Dynamics – Convair
Contractor Problems Related to Procurements Under SAMSO 73-2C	Mr. Louis Criez Boeing Aerospace
Subcontractor Problems with Primes and Component Suppliers Under SAMSO 73-2C	Mr. Sam Panella Mr. Ed Thibodeau Hamilton Standard

SUBCONTRACT MANAGEMENT OVERVIEW

by William R. Briggs
Manufacturing Division Chief
Air Force Space Division

Principal Policy References

Requirement for Subcontract Management
(AFSC DAR Sup 23-5000)

Requirement for Subcontract Management Plan - RFPs
(AFSC DAR Sup 7-2003.100)

Subcontract Management Clause - Contracts
(AFSC DAR Sup 7-150.4)

Supplier Quality Assurance Program Requirements
(MIL-STD-1535A)

Award Fee

SD Pamphlet 70-9, Award Fee Guide
- -CPAF, CPIF-AF, FPIF-AF, FFP-AF
- -Systems and Subcontract Management
- -Control of Subcontractor Design, Performance, and Schedule

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Memorandum of Agreement/Letter of Delegation

Requires AFPRO/DCAS to flow down surveillance/reporting requirements for visibility purposes.

Reviews at Subcontractor Plants

MM/PCR	PDR/CDR
PRR	Problem Solving
PAS	Management Meetings

SUBCONTRACT MANAGEMENT PROBLEMS
A PROGRAM OFFICE PERSPECTIVE

by Col Stan Kennedy
Director of Engineering
Defense Support Program
Air Force Space Division

Mission Assurance - 1978

DSP Attendees:

Engineering	7
Config Mgmt	2
Prog Control	1
Contracting	2
Aerospace	3

DSP Contractors:

President/Gnl Mgr	2
Quality Assurance	3
Material	1
Engineering	1
Subcontract Mgr	1

Mission Assurance

Objective: Achieve specification performance on-orbit up to and beyond design life.

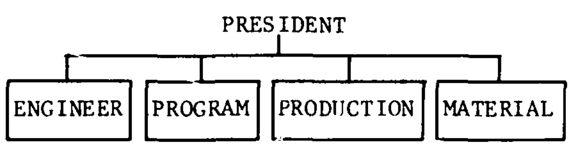
Program Office:

- o Evolves a highly redundant design.
- o Eliminates all single point failures.
- o Develops a comprehensive test program.
- o Conducts independent readiness review.

Problem Areas

Prime: Over Spec
Inadequate Monitoring
Lack of Incentives

Sub: Lack of Motivation
Ineffective Management
Misuse of Priority
Marginal Performance



Management Relationship
Prime-To-Sub

Prime:
Requires Visibility
- o Engineering - Spec/Performance
- o Schedule - Milestones
Priorities

Sub:
Requires Visibility
- o Performance
- o Motivation
- o Need Date

Solutions (?)

Communications: Tailored Specs
Firm Milestones
Monitor Progress

Incentives: Near Term
Motivators

Quality Controls: Tailored Standards
AFPRO/DCAS

Organization: Responsive to Customer

PL95-507 IMPLEMENTATION
CONTRACTING VIEWPOINT
by Col Thomas Van Meter
Ballistic Missile Office

I. Three areas for discussion:

A. Source of requirements.

B. Key points that need more emphasis in preparing small and disadvantaged business subcontracting plans for each contract.

C. Role of the mission assurance community.

II. Requirements are listed in considerable detail in the statute itself. Thus compliance is a matter of law and not just a regulatory requirement. The PCO must assure that the plan is submitted on contracts and modifications valued at more than $1 million on construction of a public facility or $500 thousand on others.

A. Approve the adequacy of the plan. (Seeks advice from the administrative contracting officer, the Small Business Administration local representative, and the DoD Small and Disadvantaged Business specialist.)

B. Review prior performance in meeting small and disadvantaged business goals as a part of the responsibility determination.

C. Determine the inductive fee where appropriate.

III. Key elements that need to be emphasized in preparing the plan:

A. Set forth goals for small business as a percentage of the total subcontracting effort. Include subcontracts charged directly to the contract and a proportionate share of the indirect subcontracts.

B. Name the program administrator and describe duties and responsibilities. Describe access of the administrator to the top level executives.

C. Describe contractor's program and what is being done to seek out and develop small and disadvantaged business sources. The plan needs to list the prospective or, when known, the actual sources, type of work performed, dollar values, and periods of performance.

D. Be prepared to report results and degree of success in meeting goals.

E. Describe records kept so that results can be reviewed.

IV. Product assurance community role:

Help administrators and procurring contracting officers establish attainable goals, but yet ones which require emphasis and management attention to attain.

Remember three "Cs":

- Candidates--find potential sources in both the technical and non-technical areas.

- Credibility--establish attainable goals. Help firms out. Tailor to needs of the firms, and don't oversell or undersell ability to meet goals.

- Competence--help small and disadvantaged firms to succeed.

SUBCONTRACT MANAGEMENT

Donald R. Fowler
Major, USAF
AF Contract Management Division

- AF CONTRACT MANAGEMENT DIVISION (AFCMD) Kirtland AFB, New Mexico
  - o One of three Contract Administration Services
    - --Defense Contract Administration Service (DCAS)
    - --Navy Plant Representative Offices
    - --Air Force Plant Representative Offices
  - o Composed of 20 AFPROs
  - o Missions
    - --Program Support
    - --Management systems surveillance
  - o AFPRO Functional Divisions
    - --Quality Assurance
    - --Engineering
    - --Manufacturing Operations
    - --Government Property
    - --Contracts
    - --Subcontracts Management
- SUBCONTRACT MANAGEMENT DIVISION (SM)
  - o Mission
    - --Program Support
    - --Procurement system surveillance
  - o Origin
    - --Need during 1960s
    - --USAF generals' initial concept
    - --1973 formed from other functions
  - o Initial SM Purposes
    - --Baseline procurement system
    - --Purely after-the-fact
- SM TODAY (STILL MULTI-FUNCTIONAL)
  - o SM accepted as a true, necessary function
  - o QA back to QA
  - o SPO support is priority
  - o Major Problems in SM today
    - --Manpower/turnover
    - --Past - no "need" for SM! (C-5A sub)
    - --Only AFPROs have SM-dedicated
    - --No training courses for SM
- PRE-AWARD PHASE OF THE SUBCONTRACT
  - o Pre-award surveys
  - o Past subcontractor performance
  - o Type of subcontract based on risk and prime (associate contractors)
  - o RFP review and subcontract management plan
  - o Emphasis on small/disadvantaged business
  - o Assess statements of work
- AWARD PHASE OF THE SUBCONTRACT
  - o Purchase Order, Interdivisional Work Authorization and Consent-to-Issue Reviews
    - --Purchase Order and subcontract defined
    - --Assess "flowdowns" (some needless costs)
    - --Designate major/critical subcontracts and Interdivisional Work Authorizations
    - --Assess cost/price analysis and negotiations
    - --Assess all functional flowdowns
  - o Initiate multi-functional delegations
- POST-AWARD PHASE OF THE SUBCONTRACT
  - o C/SCSC (what SPO needs most)
  - o Reports from delegations
  - o Closer coordination with SPOs
  - o Assess prime contractor managment of subs
  - o Visits to subcontractors
  - o Aid in manufacturing management production capability reviews
  - o Aid in production readiness reviews
  - o Strikes and workarounds

- Shortages and long-lead planning

- BENEFITS TO CONTRACTORS
  - Intermediary between SPO and prime
  - Hopefully "one face to industry"
  - ASPS No. 1 being rewritten (less subjectivity)

- CONTRACTOR REACTION TO SM
  - Some ignore consents ("enough business")
  - Nobody likes auditors
  - Imposed corrective action

- FUTURE OF SUBCONTRACT MANAGEMENT
  - 50% of prime dollars in subcontracts
  - Prime's overhead forces subs work

NOTE: SPO support can be defined as: teamwork in the acquisition process for wisely spending Government money; a process of saving the SPO's time; an avoidance of duplicate effort between SPO and AFPRO; a common sense business approach based on coordination, communication, and cooperation; taking the lead in the phases of acquisition best suited for one's discipline; a cross-check, etc.

MISSION ASSURANCE WORKSHOP

April 29, 1980

THE CENTAUR PROGRAM MISSION ASSURANCE SYS

by

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1. INTRODUCTION

In order to adequately appreciate the Centaur Program's mission assurance system, it is essential to first present a summary of the program's history, responsibility and structure. The Centaur has been integrated with the Atlas and Titan IIIE boosters in what will be referred to herein as the Centaur Program. The Centaur itself is an upper stage launch vehicle having a thrust of about 30,000 lbs. provided by two engines burning liquid oxygen (LO2) and liquid hydrogen (LH2). Its development began in the fifties when the Lewis Research Center (LeRC) did much pioneering work in developing liquid hydrogen technology. In 1953, an experimental LO2/LH2 engine with 5,000 lbs. thrust was fired at LeRC. General Dynamics Convair Division (GDC) was awarded contracts to design the Centaur launch vehicle, and in 1963 the first successful flight of Centaur D atop an Atlas booster occurred under technical management of LeRC. Centaur's first mission to inject Surveyor moon landers into their translunar orbit was an outstanding success.

During the early seventies, a D-1 improved Centaur Program was completed. The objectives of the D-1 were to achieve lower boost vehicle integration costs. The Centaur D-1A (Centaur D-1 atop an Atlas SLV-3D) achieved operational status with its first launch of Pioneer II (AC-30) in April of 1973. The Centaur D-1T (Centaur D-1 atop a Titan IIIE) became operational with the Helios A launch in December of 1974. The Centaur D-1A and D-1T employ, in general, nonredundant systems. This combined with the importance of its payloads made it imperative that the program adopt and maintain a stringent program mission assurance system.

The Centaur D, D-1A and D-1T have been used to transport into space a variety of payloads. Since the operational phase for Centaur began in 1968, there have been 50 launches using the Atlas/Centaur and Titan/Centaur of which there have been 5 failures. Only two of these five failures were caused by a malfunction of the Centaur upper stage. The Centaur has been used for missions sponsored by NASA, DOD, foreign countries, and private corporations. The Titan/Centaur has been responsible for successfully placing several prestigious spacecraft into a proper trajectory to complete its mission, such as Helios A and B (probes to the Sun sponsored by the West German government), Viking A and B (spacecraft that soft landed on Mars) and Voyager A and B (space probes to the large outer planets of our solar system). These missions not only represent an investment of more than a billion dollars, but also, in some cases, had to be launched without significant compromises to mission opportunities/launch windows. The Atlas/Centaur has been responsible for successfully placing into geosynchronous orbit several communication satellites for DOD, INTELSAT and COMSAT. To a very great extent, the existence of today's international and domestic communications network is the result of a successful Atlas/Centaur launch vehicle program.

In general, the Centaur Program's structure is not unusual as far as government programs are concerned. NASA's Office of Space Transportation Systems has assigned a division of NASA's Lewis Research Center with the responsibility of (1) integrating the launch vehicle system with the payload, (2) procuring the launch vehicle hardware, (3) assuring the overall quality of the vehicle, (4) managing all prelaunch and launch activities and (5) managing all problem solving activities and necessary hardware development. General Dynamics is LeRC's prime contractor and is responsible for

fabricating the Centaur vehicle and Atlas booster. LeRC also uses the following associate contractors to supply GDC with the Government Furnished Equipment (GFE) listed below:

1. Rocketdyne Division, Rockwell International - Atlas Engines

2. Pratt & Whitney Aircraft - Centaur Engines

3. Teledyne Systems Company - Digital Computer Unit and Remote Multiplexer Units

4. Honeywell, Inc. - Inertial Platform and Electronics

Needless to say, all of the above contractors use the services of numerous subcontractors and vendors. Also, the Centaur Program uses to as great an extent as possible delegated government agencies such as the Defense Contractor's Administrative Services (DCAS) to inspect, assure the quality of hardware, and assure compliance to requirements of hardware specifications at the contractors, subcontractors and vendors. Finally, NASA uses facilities and personnel at Kennedy Space Center (KSC) to alunch these vehicles. The program structure for a Titan/Centaur launch vehicle was very similar with the exception that the Martin Marietta Corporation serves as an associate contractor supplying GDC with a Titan IIIE booster in place of the Atlas booster.

Program related activities of the above organizations are centered around a document called the Mission Assurance Plan (MAP). The MAP is a contractor prepared and government approved document that describes tasks the contractor will do to assure mission success. The MAP is based on the government's contract requirements, the contractor's operational methods and organizational elements involved. The MAP is divided into management, engineering, and quality tasks and for each task indicates customer requirements, implementing responsibilities, implementation methods, evaluation criteria, reference to applicable specifications, and reference to customer documents that give detailed instructions. The MAP was prepared by GDC for NASA and the Space Division (SD)/USAF. The MAP applies to multiple contracts for space launch vehicles and related services.

Thus, it can be accurately stated that the Centaur Program possesses a structure similar to most large-scale high reliability programs. Therefore, as a result of its excellent success record (90 percent success), its possessing few redundant systems, and its complex structure, the mission assurance experiences of the Centaur Program should be of interest to most major NASA and DOD high reliability programs.

II. CENTAUR PROGRAM MISSION ASSURANCE SYSTEM

The success associated with the Centaur Program is the result of the program's strict adherence to sound design practices and configuration control, realistic specifications, its establishing the team concept not only among the government and contractor personnel but also, where possible, at the subcontractors and vendors, and its ability to detect and resolve problems. It would be instructive to discuss these mission assurance principles as they apply to the Centaur Program in more detail. Because the Centaur was developed by NASA for space use, and the Atlas and Titan IIIE were developed by DOD for weapons use, these principles apply in different degrees to the various stages of the Centaur Program launch vehicles. For instance, the design philosophies outlined below are more directly related to the Centaur rather than the Atlas or Titan IIIE. However, the Centaur Program has attempted to apply these principles to all the stages as thoroughly as would be reasonable. Most important is the fact that such an integration of launch vehicle stages, each having a different heritage, made it obvious that intense quality verification emphasis would be needed for mission assurance.

The design has a direct effect on the reliability, quality and safety of a system. In its design phase, close attention was given to the Centaur reliability, quality and safety characteristics; in many cases, by engineers specializing in these areas. Many different analyses such as hazard analyses, worst-case analysis, and failure modes and effects

analyses were conducted to maximize the Centaur's reliability, quality, and safety characteristics. Also, design criteria which specifies safety/performance margins such as structural factors of safety and electronic parts derating were established before the design was undertaken and strictly adhered to during the design. The design of all program hardware did include consideration of future testing in order to provide for obtaining adequate data concerning the test. For example, test points were conveniently located in hardware so that parameters such as critical voltages, currents, pressures, temperatures, and flows could be monitored during a test with the smallest possible inconvenience.

Testing is extremely important to and occupies a large part of the Centaur Program activities to ensure reliability of the components, subsystems, systems and the overall launch vehicle. The Centaur Program not only employed extensive testing during the vehicle hardware design (Design Verification Testing) and qualification (Qualification Tests) but also to berify the quality (Acceptance Testing) of all hardware and each vehicle. The program uses design verification testing to "fine tune" the design and characterize the performance of the design. Much care is used in performing flight qualification tests which include functional, environmental, stress limit and life tests to insure the hardware can satisfactorily withstand conditions more severe than it is expected to experience in acceptance testing and normal flight operations. For example, in vibration testing, it is normally required that the design be capable of surviving at least 1 1/2 times the expected flight vibration levels. Much effort was expended early in the program, and still is, to seek improvements in acceptance testing to insure:

1. All test environments exceed those of succeeding tests and final launch.

2. No test condition degrades the hardware.

3. All hardware is tested as it will perform.

4. All hardware is adequately monitored to insure proper performance and to locate any malfunction.

Programs, no matter how mature, will always experience changes in design, materials or processes. The Centaur Program is no exception and has developed a formal method for controlling the configuration of the vehicle. The Centaur configuration system can be broken into the three main functions of change evaluation, implementation and documentation. The Centaur Program prime and associate contractors are required to submit to LeRC a description of any change, justification for change, and sufficient data to evaluate the effect of the change on the vehicle performance. This package is evaluated by the LeRC engineer responsible for the hardware where the change is required. Once he is satisfied, he submits the change requests to an Engineering Review Board which formally rules on whether the change should be implemented. The Engineering Review Board is a formal board composed of launch vehicle management engineers and reliability engineers. After the change is approved by the Engineering Review Board, it is submitted to the Launch Vehicles Change Board (LVCB) where it is evaluated with respect to schedule and cost as well as technically. LVCB also assures that the change will be properly documented.

Realistic specifications are the backbone of the Centaur Program's hardware. Specifications must on one hand assure obtaining the most reliable piece of hardware and on the other hand not be so restrictive as to cause the most qualified vendors to not bid on fabrication of the device. Realistic specifications are developed by first defining the critical materials, processes, and testing and then controlling these items adequately through the specification. This close scrutiny of the specification is applicable to systems, subsystems, and piece parts. Finally, ongoing control of the materials, processes and testing must be assured by the contractor, subcontractor or government representatives (DCAS).

In a majority of cases, the Centaur Program found military specifications satisfy the above requrirements. Therefore, they should be used as frequently as possible in a high reliability program.

In certain areas (electronics parts) the Centaur Program found military specifications could be augmented and additional confidence established by additional hardware testing. Whenever no military specifications exist to control an item needed, the Centaur Program has expended considerable effort to develop realistic specifications. In these cases, Centaur Program contractor and government representatives have worked with subcontractors and vendors to develop specifications that assure adequate control of materials, processes and testing. These negotiations are usually not easy and require careful compromises.

One of the most important assets of the Centaur Program is the team concept. The team concept on the program has been most successfully applied to the group of engineers the program refers to as system engineers. Each major vehicle system has assigned to it a contractor and government system engineer. With respect to that system, the government system engineer and his contractor counterpart are responsible for the following:

1. Mission Integration Interfaces

2. Problem Solving

3. Evaluation and Qualification Testing

4. Factory Acceptance

5. Product Reviews

6. Flight Readiness Status

7. Launch Support

8. Flight Data Reduction Analysis

9. Flight Report

10. Contract Support

11. Liaison with KSC and Contractor

The Centaur Program has promoted the team concept effectively by practicing the following:

1. Showing with positive action (recognition awards, promotions) that the system engineer is important in achieving mission assurance.

2. Providing definite direction through management instructions to the systems engineer.

3. Keeping the systems engineer informed on not only technical issues but management issues also.

The Centaur Program has found that developing the team concept among subcontractors and vendors much more difficult. Because the subcontractor and vendor are more removed from the program and because their main job and interests do not necessarily align themselves with those of the program, they can fail to appreciate the goals or thoroughly practice the policies of the program.

The Centaur Program has found that the most effective way of developing the team concept at the subcontractor or vendor is through visits by government and contractor representatives. During these visits, the representatives inform the subcontractor or vendor of the current developments in the program and instill in their personnel the idea that they are making a major contribution to the success of the program - which they are. Usually, after a visit, a letter is sent with photographs of important developments so it can be posted at an appropriate place to try to contact as wide a spectrum of employees at the vendor or subcontractor plant as possible.

Problem awareness and solving have contributed tremendously to mission assurance on the Centaur Program. Although the problems on the program have occurred in every technical discipline and at various levels of seriousness, the manner in which they are brought to management's attention, assigned a priority, and closed out is similar and formal.

Problem awareness in the Centaur Program begins with providing the necessary checks at the contractor and associate contractor to insure that all failures are detected. The program uses prime contractor and associate contractor quality personnel, resident engineers, daily contact between the program's system engineers, and personnel of delegated government agencies (DCAS) to surface

failures. With such a system, a test falure or receiving inspection (subcontractor or vendor) problem is quickly located and the subsequent analysis receives adequate and expert attention. To detect problems occurring at a subcontractor or vendor, the program relies on contractor source inspectors as well as DCAS. Historically, the program has found it more difficult to surface these problems. However, it has found that certain signs such as rescheduling of delivery dates or lack of cooperation usually are indicative of a problem with the product and, therefore, a visit to the subcontractor or vendor should be arranged. An extremely important aspect of problem awareness is maintaining good failure records. Such records make it easy to assess whether failures are generic; i.e., failures that possess a common link.

Many of the test failures occurring on the Centaur Program are random in nature. For instance, a piece of electronic hardware may fail because of a diffusion defect in a transistor. Such a phenomenon is possibly the result of a piece of dirt findings its way into the processing of the transistor's wafer which is a random occurrence and is not representative of other transistors fabricated by the vendor unless many of the vendor's transistors fail as a result of diffusion defects.

At certain times, however, the program has found that a certain group of failures possess a common link and, therefore, are generic. Whenever such a link exists between failures, steps must be quickly taken to:

1. Determine the cause of failure

2. Bound the problem

3. Develop effective corrective action

To insure that the above activities are carried out adequately, the problem is elevated by management. Elevation allows management to track the progress on bounding and solving the problem and allows them to assure the corrective action is in concert with the overall program mission assurance philosophy and goals.

To determine the cause of failure and also bound the problem, the program uses all avenues available to it which include:

1. Sophisticated failure analysis techniques and tools

2. Analysis of relevant system and component tests

3. Similar component analysis

4. Subcontractor or vendor visits to review component processing and materials

The goal of the above activities is to obtain mutually supportive data to determine the cause of the problem, define its boundaries, and develop effective corrective action. Engineers involved in a particular problem report to the Centaur Program management as frequently as daily if the problem has much urgency or visibility associated with it, or as infrequently as weekly if the problem is rather minor. The program does, however, conduct open Problem Review meetings and closed Problem Review meetings approximately monthly to insure all problems are being or have been adequately solved. During these reviews, subcontractor and vendor problems are surfaced and steps for their resolution planned. Finally, the investigations that resolved the problem and corrective actions are documented in a problem closeout memorandum. The program will not conduct a launch unless all problems associated with the vehicle to be launched are closed.

The NASA program personnel insure that failure information is transmitted between the prime and associate contractors to assure that effects of the problem on the overall program or vehicle can be evaluated. The program, through its reliability engineers, inputs failure and problem data into the Government Industry Data Exchange Program (GIDEP) and monitors it to assess the latest ALERT data's effect on the Centaur Program. Finally, the program's engineers and management are in frequent contact with other NASA programs to inquire about any problems or concerns they are invovled with.

Whenever a failure occurs during a launch, regardless of whether the failure is of a generic nature or not, a very formal resolution is necessary. This is, of course, a result of the visibility of such a failure. Under such conditions, the steps of the flight failure investigation methodology are listed below:

1. Establish Failure Investigation Teams

    a. NASA/LeRC
    b. Contractors

2. Establish NASA Review Board

3. Analyze flight data

4. Recover and analyze flight hardware

5. Develop failure tree

6. Develop possible failure scenarios

7. Formulate and perform investigative tests

8. Consult other experts

    a. Within NASA
    b. Nationally known authorities

9. Define the most probable cause of the failure

10. Initiate corrective actions

11. Respond to the NASA Review Boaro recommendations

12. Report to NASA Headquarters on findings

13. Finalize and implement corrective actions

III. PROGRAM EXPERIENCES AND THEIR IMPACT ON MISSION ASSURANCE SYSTEMS

In order to understand more fully how program experiences have affected the Centaur mission assurance system, the overall experience of the program with regard to mission assurance will first be discussed. This discussion is based on a categorization of flight readiness problems during the period from early 1977 to late 1978, a period of 1 1/2 years. Flight readiness problems are defined as those discussed with top LeRC management, payload customer, and NASA Headquarters personnel. During this 1 1/2-year period, 46 flight readiness problems were presented. Seventeen problems were associated with mechanical systems, whereas 29 problems were associated with avionics systems. Our conclusion is that this mix represents the relative complexity (high part density with associated single point failure modes)of avionics systems over mechanical systems. If one were to classify these 46 problems according to where they were found, one would get the distribution indicated in Table 1:

This type of classification indicates that, because the avionics system is more readily checkable than the mechanical system and can operate before flight as an integrated system, more avionics problems are found before flight. A corollary of this fact is that, because the numerous mechanical components (i.e., propulsion systems, structures, etc.) operate as an integrated system only in flight, more mechanical problems are found in flight.

This justifies the Centaur Program utilization of flight simulation techniques as extensively as possible during ground checkout and adequate instrumentation to evaluate flight problems. It should be pointed out that all flight readiness review problems in Table 1 did not affect the success of the launch. In fact, only one of the 13 in-flight problems in Table 1 did affect the flight success.

If one classified this same group of problems according to cause, the result would be that shown in Table II.

This classification reveals that the manner in which hardware is processed contributed to a majority of program problems. This data provides the justification for the program expending much effort to thoroughly and periodically review contractor, subcontractor, and vendor fabrication procedures (through some formal audit program) in order to reduce process caused problems. These reviews or audits are usually performed by contractor/government teams. The members of the teams

are experienced in the fabrication and quality procedures associated with a particular piece of hardweare. During a particular audit the team will review subcontractor/vendor activities concerning a particular piece of hardware such as the overall fabrication process, critical processes, quality practices, and adequacy of hardware records.

This same group of problems was finally classified in accordance with who was mainly responsible for the cause. The results of this classification are shown in Table III.

Table III indicates that vendors contribute to a substantial proportion of the total problems. This justifies the program's attempt to apply its mission assurance system to the vendors as well as the contractors (associate and prime).

Placing problems into categories as pointed out above is helpful in evaluating the program's mission assurance activities as well as pointing out to management where additional effort should be exercised. An example of this is the decision by the program's management to conduct an electronic parts improvement program. This is an example of how a changing environment external to the program made it necessary to adjust the program's mission assurance system. In this particular case, the changing environment was the the change in the major customer of the microelectronics industry from the aerospace user to the commercial user, and the industry changing from fabricating high reliability devices on custom lines to fabricating these devices with mass production techniques.

It was concluded as a result of classification of major program problems during the mid 70's that electronic piece parts were causing an inordinately large percentage of the important problems. For instance, in 1975 about 30 percent of of flight readiness problems were due to electronic piece parts. Furthermore, this percentage seemed to be on the increase. The program management decided to change the mission assurance system in this area to hopefully reverse this trend. At this time, the most significant mission assurance characteristic of electronic parts was to procure them using, wherever possible, specifications and vendor checks developed from the manned space program.

The first phase of this activity consisted of forming an electronic parts improvement task force in the fall of 1975. Its objective was to evaluate electronic parts activities of the program's contractors who use relatively large amounts of electronic piece parts. The task force membership consisted of electronic piece part engineers from LeRC, GDC, Teledyne, Honeywell, George C. Marshall Space Flight Center (NASA's lead Center for electronic piece parts) and Aerospace Corporation. The task force's method of operation was to first bring the contractors together to have open exchanges on their experiences in all their electronic piece parts activities, and secondly, to visit many of the program vendors to inform them of the program's objectives and see how within the framework of their operation these objectives could be satisfied.

The task force concluded that the contractors should strive for commonality in parts activities such as parts usage, specfication, special testing, and vendors. Secondly, the task force concluded that the contractor source inspection should be improved. It felt this could be accomplished by sending source inspectors to the contractors' home plant more often for more contact with the parts engineers in an environment where he could learn more about the parts he is involved with, problems encountered with these parts, and changes in methods of testing parts. Visits to the vendors revealed that any of the program's vendors were capable of fabricating a good part at any given time or on the other hand, a bad part at any given time. This meant better parts could not be obtained by changing or eliminating vendors, but might be obtained by better monitoring of the particular lot of parts procured. The task force also found that special NASA surveillance of vendors was rapidly declining. The program in the past had relied heavily on this surveillance which was the result of the manned space programs, which by this time (about 1975) were nearing completion. The final major finding of the task force was that requiring special fabrication by the vendor

was undesirable. Special fabrication usually meant a part had to be fabricated on a less capable line or at least taken from the more capable lines for special processing which meant its quality could be reduced due to this type of processing.

As a result of these task force findings, the program decided to direct the contractors to convert wherever possible to NASA standard devices (MIL-STD-975) and to further increase the quality of these devices by conducting a rescreening of these parts at a preselected screening laboratory. The program felt this would promote part specification and testing commonality among contractors. The program also decided through specification and monitoring to tighten its control on part fabrication wherever it was consistent with activities at the vendor fabrication line. For example, the program required the fabrication of all its parts be done in this country and sample internal lead bond pull test be conducted on each lot of parts. In addition to controls such as these, the program decided to upgrade source inspection in order to increase its control on part fabrication.

In order to monitor vendor capability and effectiveness of source inspection and to detect gross part inconsistencies, the program required device construction data sheets be supplied with the devices procured, and a destructive physical analysis be conducted by the contractor or a designated laboratory on a sample of the vendor's lot of devices procured. This also insured that any changes in construction or gross deficiencies could be detected and evaluated early. Finally, the program decided to create a Launch Vehicle Electronic Parts Steering Committee to monitor all electronic parts activities such as rescreening and results of the destructive physical analysis. These efforts had a very noticeable effect on the quality of electronic parts by 1978. In that year, there were 21 flight readiness problems. However, only one of these could be classified as an electronic piece part problem.

Sometimes a program can improve its mission assurance system by taking advantage of unique capabilities and experience that exist within its parent organization. This turned out to be the case with the Centaur implementation of the microelectronic hybrid parylene passivation program. This activity has visibly improved the Centaur Program mission assurance as well as other high reliability programs both within NASA and private industry. The problem which gave birth to this activity was numerous acceptance testing failures in the launch vehicle digital computers caused by conductive particles in hybrid microcircuits. These failures were the result of (1) a lack of glassivation of the hybrid microcircuit die, (2) improved methods of vibrating the computer as well as techniques for detecting a failure and (3) package design that made it difficult to control solder particles resulting from the hybrid cover seal process. Changing any one of these items to reduce the failures would either compromise quality or seriously impact the program both from a cost and schedule standpoint.

To resolve this problem, the Centaur Program initiated an activity aimed at passivating the hybrid microcircuits by using a coating material called parylene. The parylene coating material was chosen mainly because its important characteristics, shown in Table IV, applied favorably to the hybrid microcircuits in question.

The above characteristics coupled with unique in-house (LeRC) expertise made parylene especially attractive in this application.

Since the vendor who fabricated the hybrid microcircuits had no experience in the parylene process, a coater had to be installed at his facility. After coater installation, hybrid microcircuit tooling and processing had to be developed under the direction of government program and parylene engineers. Also, tests were conducted to determine if parylene or the manner in which it was being applied had any effect on the hybrid microcircuits.

Once the above activities were satisfactorily completed, qualification testing was began at the part level to satisfy the program requirement; that neither unqualified parts or processes shall be used on the vehicle. This qualification program was patterned after the standard military qualification for microelectronic circuits,

except operating life tests and high temperature storage were conducted for 2,000 hours rather than the usual 1,000 hours.

The parylene passivation program has greatly improved the quality of the launch vehicle digital computer. Since its implementation, no hybrid microcircuits coated with parylene have had a particle induced failure; and since it was specially designed for hybrid microcircuits which caused digital computer vibration failures, a vibration failure now is a rare occurrence. Furthermore, because particle failures are usually intermittent, failure analysis results were not always conclusive and large amounts of hardware occasionally had to be declared nonflight - a costly and schedule impacting alternative. With the implementation of parylene, this no longer occurs.

Thus far, I have discussed techniques and activities implemented on a high reliability program for the sole purpose of mission assurance; i.e., preventing a failure which causes the program to not meet its primary mission.

At times, such efforts do not prevent this from happening and the Centaur Program is no exception. How a program reacts to such a serious occurrence and recovers, and defines the "lesson learned" corrective action, is certainly a subject which should be addressed.

My example will be the most recent Atlas/Centaur failure. On September 29, 1979, an Atlas/Centaur (AC-43) was launched with the objective of placing an INTELSAT IV-A communication satellite into a geostationary orbit. The flight was terminated 55 seconds into flight when the vehicle self-destructed. From initial reviews of the data, failure scenarios were developed and analysis, tests and data reviews were immediately conducted to evaluate these potential failure scenarios.

The failure analysis was significantly aided by the fact that the vehicle was destroyed so early in flight. It had not traveled far downrange and much of the hardware from the booster section which the failure scenarios were centered around could be recovered from the Atlantic Ocean. Concurrent with recovery of booster hardware, examinations and supporting tests conducted at GDC indicated that the area nearest the booster gas generator was exposed to the highest temperatures. The recovered gas generator was delivered to Rocketdyne, the associate contractor responsible for the booster engines, and detailed testing and examination revealed only one leak source in the gas generator system, this being a crack in a brazed joint in the gas generator outlet manifold assembly.

Review of the paper history assoicated with the gas generator manifold assembly revealed it was procured as one of a last order of nine items from a vendor of Rocketdyne. Furtehrmore, it was learned that the brazing of the joint was performed by a second vendor in 1971.

This second tier vendor has since gone out of business, but interviewing the the ex-owner indicated that:

1. Braze furnace atmosphere was hydrogen.

2. Carbon tooling was not disallowed for brazing.

3. Carbon tooling was frequently used in hydrogen atmosphere.

4. Parts were received precleaned.

As a result of the data accumulated above and subsequent matallurgical analysis of the failed joint, it was concluded that:

1. The joint was carburized and sensitized.

2. Extended exposure to corrosive environment at ETR had occurred.

3. Fracture was a result of intergranular corrosion.

4. Carburization and sensitization were most likely caused by a contaminated brazing process.

As a result of this failure and subsequent analysis, the program implemented the following corrective actions:

1. Conducted a review of vehicle hardware material processing.

2. Developed a nondestructive test to identify sensitized hot gas manifold braze joints.

3. Changed contractor/vendor specification to eliminate use of carbon fixtures.

In conclusion, it is important to note that even a program operating suc cessfully several years with formal well-developed mission assurance practices is vulnerable to a failure. Therefore, it must continually be vigilant to detect the quality defects that exist in any system and be ready to improve its mission assurance system as a result. In this case, the Centaru Program decided to:

1. Review and improve process controls at critical sub-tier vendors.

2. Periodically certify critical sub-tier vendors.

3. Use coupon samples to monitor critical processing.

In spite of the seriousness of this type of failure, its visibility, and its source of embarrassment to the program, it is comforting to be part of such an effective team effort. After the failure, the Centaur team (government, contractor, and vendor) worked together in a very cooperative and efficient manner to resolve the problem. Since this failure, 10 successful Atlas/Centaur launches have ocurred. This is an excellent testimony that the program has successfully recovered from the failure.

IV. CONCLUSION

An effective program mission assurance system must have a strong base which the Centaur Program has in its Mission Assurance Plan. As pointed out herein an effective plan must be dynamic and, therefore, must provide within its basic plan provisions for change, through mission assurance improvement activities. In this paper, we have discussed some of the more prominent recent activities which have improved the mission assurance of the Centaur Program. Although these activities were initiated to meet widely different program needs, were quite different in the nature of their work, involved different disciplines, contractors and vendors, they do have the following in common:

1. A customer (NASA-LeRC) familiar with its hardware and able to identify a specific program goal to better meet the objectives of the program.

2. Contractors, subcontractors, and vendors who understand and appreciate the objectives of the program and have a strong desire to cooperate with the Government and each other to satisfy a specific goal.

3. An existing mission assurance system which encourages periodic assessment of;

a. subcontractors and vendors

b. hardware improvements and changes

and allows changes to the program associated with these items after they have been adequately evaluated.

These characteristics have been essential to the Centaur mission assurance system and its continuous improvement. Without such an effective mission assurance system, the Centaur Program would not be the mature and successful program that it is today.

TABLE I

WHERE FLIGHT READINESS PROBLEMS ARE FOUND

SYSTEM \ WHERE FOUND	FACTORY	LAUNCH PAD	IN FLIGHT
Mechanical	2	7	8
Avionics	16	10	3

TABLE II

FLIGHT READINESS PROBLEM CAUSE

SYSTEM \ CAUSE	TEST	PROCESS	MATERIAL	DESIGN	OTHER
Mechanical	2	8	2	2	3
Avionics	2	15	0	4	8

TABLE III

FLIGHT READINESS PROBLEM RESPONSIBILITY

SYSTEM \ RESPONSIBILITY	VENDOR*	CONTRACTOR	UNKOWN
Mechanical	6	10	1
Avionics	11	17	1

* Includes subcontractors

TABLE IV

IMPORTANT PARYLENE CHARACTERISTICS

Thin Uniform Coating Thickness
Resistant to Microelectronic Processing Chemicals
Mechanical and Electrical Properties Acceptable to Hybrid Microcircuits
Stable in Inert Atmosphere
Application Relatively Simple and Quality Easily Controlled

An Overview of Space Division Part Management and Technical Requirements

Sgt Clifford Schroeder
USAF Space Division

Space Division is developing and improving the requirements for space quality parts which are needed in order to achieve success on space missions. In this presentation, I will discuss the principal management and technical requirements and their implementation at the prime and subtier contract levels. Subtier contractors include subcontractors, suppliers, and vendors.

Unique Features of Space Programs

1. Long mission life - 10 year goal

2. No maintenance in space

3. Complex, high-cost equipment

4. Use advanced technology

5. High-cost development tests and models

Most of you are familiar with the unique features of space programs, but I would like to review them briefly. The new STRATSAT and DSCS III programs have a design life of 10 years with a required life of 7 years. No operational maintenance is available in space - yet. Therefore, we must build them right the first time. Spacecraft have numerous subsystems and components using new complex piece parts and exotic materials. The vehicle's parts count reflects their increased complexity. IDCSP, a forerunner of the DSCS spacecraft had 4700 parts per spacecraft. DSCS II increased to 36,000 parts, and the current DSCS III anticipates 150,000 parts. Although some of this increase is to provide redundancy for reliability improvement, the trend to increase complexity is clear. The cost for one spacecraft and launch vehicle is on the order of $100 million.

Achieving additional performance is usually a program objective - more channels, a larger number of functions, and more autonomy requiring greater on-board data processing capability. By advanced technology relative to electronic piece parts, I mean microprocessors, complex hybrid circuits, large scale and very large scale integrated circuits (VLSI). These types of parts need high reliability and strong management requirements.

Engineering, breadboard, and development models and tests also are becoming increasingly complex and expensive. In some instances, we have had a quarter of a million dollars invested in one development model and test.

Elements of the Parts Problem

1. Long mission life, complex equipment, requires lower part failure rates to achieve mission reliability.

2. Piece parts can be single point failure modes.

3. Purchase of "space" electronic parts is difficult.

4. Parts failing during assembly and test increase costs, delay schedules, indicate low reliability of equipment.

5. Part failures have caused significant mission and ground equipment failures.

The constraints and requirements at the system level are reflected in the requirement down to the piece part level.

When the mission life and parts count are both doubled, the parts failure rate must be reduced to one fourth of its value to achieve the same mission reliability. If the reliability is also increased, a further improvement in the parts failure rate is needed.

Single point failure modes can be alleviated with redundancy but redundancy alone won't achieve mission success.

Some of the purchasing difficulties experienced are no qualified source from which to purchase a MIL Spec part, nonresponse by vendors to purchase requests, long lead times--on the order of 15 to 18 months--

and low quality parts. We recognize that purchasing is difficult, and are working on Class S procedures and surveillance requirements to alleviate those difficulties.

In addition to the repair work and replacement part, the actual cost of part failures during assembly includes the work by the quality inspectors, material review board, corrective action board, and administrative overhead. Many programs don't investigate the part failures during equipment fabrication, but sometimes these failures were indications of a hardware problem.

Mission failures attributed to piece part failures were described by Col Schlosser and others at the 1978 Mission Assurance Workshop. Last year, at least one ABRES flight test anomaly was attributed to a piece part failure.

<u>SD Approach to Improving Space Parts Reliability and Availability</u>

1. Comprehensive part management program for all parts.

2. Standard "space quality" technical requirements.

3. Identification/prevention of all part failure causes.

4. Development of Class "S" (space) MIL Standard parts.

5. Space part coordinated procurement by prime contractors.

The recommendations of the parts panel at the 1978 workshop have been a strong influence on Space Division's approach to improving the reliability and availability of parts for use in space systems. This approach includes extensive management by each program and prime contractor of all parts used in the space hardware, as well as developing and implementing "space quality" technical requirements for all standard and nonstandard parts. These requirements include standardized test methods, the identification of all known causes of parts failures, and any known methods of preventing them, such as scanning electron microscope (SEM) inspection and wafer lot tests.

When buying small quantities of parts, as is typical on space programs, coordinated procurement has demonstrated advantages for obtaining high reliability parts--less documentation, better schedules, and fewer samples required for destructive testing.

<u>Documented Parts Program Requirements</u>

1. SAMSO-STD 73-2C

   a. Initial standard for space parts
   b. Management, technical requirements

2. MIL-STD-1546 - Management Program for Space Parts.

3. MIL-STD-1547 - Technical Requirements for Space Parts.

Some management practices have proven more effective than others for obtaining high quality space parts. These practices were defined and documented in SAMSO-STD 73-2C to provide an organized structure for parts control on space and missile programs. Those requirements have been revised to include better technical requirements and management techniques.

<u>Revision of SD Parts Standards</u>

1. Part program management (MIL-STD-1546).

   a. Expansion of SAMSO-STD 73-2
   b. Includes AF parts control requirements (MIL-STD-965)
   c. Requires comprehensive parts management by contractor

2. Technical (spec) requirements for contractor parts (MIL-STD-1547).

   a. Section for each part type
   b. Refers to space quality MIL Spec requirements
   c. Incorporates lessons learned/failure preventions

The management requirements are written in MIL-STD-1546, the technical requirements for the parts are in MIL-STD-1547. These documents are scheduled for publication this year and have been through several coordination cycles with the Space Parts Working Group which includes representatives from Industry, NASA, and the military.

We don't claim to have developed perfect requirements, but we are improving them.

MIL-STD-1546 - Management Requirements

1. Parts, materials, processes control, and standardization program.

2. PMP control board.

3. PMP program plan.

4. Parts selection criteria.

5. Documentation review/approval.

6. PMP list.

7. Coordinated/centralized procurement.

8. Supplier control and surveillance.

9. MPCAG participation.

These are the principle requirements of MIL-STD-1546. I will expand on some of them later.

Management responsibilities are assigned to the PMP control board to provide high visibility into all parts control efforts.

The program plan describes in greater detail than the military standard how the requirements will be implemented and satisfied.

In order to manage the parts control program, the parts board reviews and approves required documentation such as the parts program plan, part specifications, non-standard part approval requests, and reports on schedules, tests, and failures.

The functions of the military parts control advisory group are described in Appendix E to the military standard. This group from the Defense Electronics Supply Center (DESC) provides advise on the use of military standard parts.

MIL-STD-1547 - Technical Requirements

1. Interim method to obtain space qualified parts not on Class "S" QPL.

2. Limits of use of "unreliable" part types.

3. Application and design.

   a. Derating, "end-of-life", mounting

4. Part design/construction.

5. Quality assurance provisions.

   a. In-process inspections/controls
   b. Group A screening 100%
   c. Group B lot conformance
   d. Qualification tests

6. Destructive Physical Analysis (DPA).

MIL-STD-1547 contains the technical requirements to be put in the specifications used for purchasing the parts.

Some application requirements for the parts use in the end item are included. The "end-of-life" requirement enables a circuit to perform as specified until aging of the parts electrical parameters exceed the tolerances specified.

The requirements were compiled using information from lessons learned and corrective actions on failures. These indicated some "unreliable" part types which require procuring activity approval for use.

Several tests which are done on a sample basis in present military standards have been changed to 100% screens. Qualification tests apply to a part type and usually reference a military standard.

Destructive physical analysis, the dissection and examination of a part, is an effective method to detect contamination, poor workmanship, and design changes. It detects semiconductor device problems like counterfeits, weak bonds, and die attach problems. The DPA requirements are documented in MIL-STD-1580 which is scheduled for publication this year.

The need for strong management and "failure free" parts does not lessen at subtier levels, but how to apply or implement the requirements may change as the scope of the efforts become more specialized. Having presented a brief overview of SD parts requirements, the remainder of the presentation will offer some examples of application of these requirements at the various contract levels.

MIL-STD-1546

1. Applies in total to prime as tailored by SOW.

2. Applies to sub as tailored by SOW except where prime takes action in lieu of sub, e.g.,

   a. Manage program parts list
   b. Chair PMPCB

3. Does not apply directly to parts manufacturers.

The prime contractor becomes responsible to the procuring activity for satisfying the management requirements of MIL-STD-1546, as tailored in the statement of work. Some requirements specify functions to be performed by the prime contractor--for example, managing the program parts list and chairing the PMPCB. For other requirements, the prime may delegate authority to the subtier contractors which become responsible to the prime contractor. That delegation does not change the responsibilities of the prime contractor to the procuring activity.

Achieving space reliability must be a cooperative effort with all contractors, subcontractors, and vendors doing their part to assure standard space quality parts are selected, specified, and procured to standard, space quality requirements.

MIL-STD-1547

1. Applies to all parts (other than JAN branded, Class S parts from SD PPL).

2. Applies to subs the same as primes except where waived by PMPCB and procuring activity.

3. Applies to parts manufacturers as included in program part specs.

The management requirements of 1546 do not apply to the piece part manufacturers. A different set applies to them--the technical requirements of MIL-STD-1547. These requirements apply to all contractor specified parts to assure these "non-standard" parts, if approved by the PMPCB, are procured to requirements used to buy the MIL-Standard Class S and JAN S parts. In its present form, MIL-STD-1547 applies to all electronic part types--relays, inductors, resistors, capacitors, as well as integrated circuits and semiconductor devices.

Except where waived by the procuring activity and PMPCB, these requirements for space quality parts apply through all subtier contracting levels to the part manufacturer who satisfies the requirements as specified in the applicable purchasing document.

Parts, Materials, and Processes Control Program

Prime Contractor	Subtier Contractor
Plan, establish, conduct a PMP control program	Satisfy PMP control requirements imposed by contract flowdown
Responsible for supplier surveillance	Perform surveillance if required
Establish operating procedure to be followed by the PMPCB	Provide member for PMPCB
Identify responsibilities and functions for the PMP effort	Perform functions as required
Develop, provide a PMPCB master task schedule	Each subtier contractor provide a schedule for the subcontracted effort

The above list identifies some of the major elements of the PMP control program and compares the responsibilities of the prime and subtier contractors.

For example, the prime plans, establishes, and conducts the program. The subtier contractor satisfies the responsibilities described in the subcontract.

Also, each subtier contractor provides a schedule of his effort enabling the prime to develop a schedule for the total program.

Parts, Materials, and Processes Control Board

Prime Contractor	Subtier Contractor
Establish a PMPCB	
Chair the PMPCB	Provide member

Establish operating procedure	Comply with procedure
Establish program PMPSL	Provide inputs for PMPSL
Evaluate NSPARs, deviations	Prepare, submit NSPARs, deviations
Review failure reports, MRB actions	Inform PMPCB of parts problems

Prime Contractor	Subtier Contractor
Schedule, coordinate, administer PMPCB meetings	Attend, provide technical support
Prepare PMP documentation when contract requires	Same
Ensure subtier contractors support PMPCB	Maximize use of standard PMP, accomplish supplier surveys as required

Comparing the respective parts control board responsibilities, the prime chairs the board, the subcontractor's members participate. The subtier contractors provide information such as NSPARs and deviations for the prime to evaluate. Contractually required documentation must be prepared by both.

PMP Selection Criteria

Same criteria applies to prime and subtier contractors.

Preferred: Standard parts

Preferred parts list - Class "S", JAN S

Alternate: Substitute Class "S" parts

Space Division preferred parts list
Requires NSPAR, PMPCB approval

Preferred part types

Space Division preferred parts list
Require NSPAR, PMPCB approval

Purchase to military specification and MIL-STD-1547 requirements

If needed: Nonstandard parts

Require NSPAR, PMPCB approval
Require parts specification
Purchase to MIL-STD-1547 requirements

Appendix C to MIL-STD-1546 describes the selection criteria for parts used in space systems. The criteria applies equally to the prime and subtier contractors. The preferred parts list is Appendix D to MIL-STD-1546. Until it is issued, the current preferred parts list is SD-STD 73-4B.

Coordinated Procurement

Prime Contractor	Subtier Contractor
Organize, manage CP program	Participate as required by contract, supplemental agreements
Establish list of CP parts	Submit part types, quantity, need date
Negotiate common purchasing agreement with PMPCB approved suppliers	Purchase from approved suppliers
Submit documentation for procuring activity approval	Provide information as required

Common purchasing agreement
Cost allocation plan

Manage incoming inspection requirements	Perform required inspections plus additional inspections as desired for confidence

Coordinated procurement is defined as the combined effort of the prime contractor and subtier contractor on a given program to purchase parts through the use of common specifications, common purchase agreements, and unified management. The Space Division's Commander's Policy of using coordinated procurement was another result of the recommendations from the

1978 Mission Assurance Workshop. Most contractors who have implemented it saw the advantages mentioned earlier. Additional advantages include less inspection manpower and lower costs. The current requirements for centralized procurement are documented in Notice 3 to SD-STD 73-2C.

The prime contractor organizes and manages the coordinated procurement program. The subtier contractors participate as required in the subcontract document and supplementing agreements. The subs submit information on the parts they need and the prime prepares the combined list of coordinated procurement parts. The prime contractor has overall management responsibility for incoming inspection requirements. The subtier contractors perform the inspections required and they may perform additional inspections as desired to increase their confidence in the parts quality.

Supplier Control and Surveillance

Prime Contractor	Subtier Contractor
Perform surveillance or designate representative	Perform surveillance if required
Verify fabrication to manufacturing baseline and purchasing document requirements	Same
Monitor change requests	Same
In-process, final inspections	Same
Qualification requirements	Same
Notify PMPCB of problems	Notify prime and PMPCB of problems

Supplier control and surveillance is defined as the monitoring by the contractor or of his designated representative, of the manufacturing, inspection, and test operations of a supplier, based on preestablished criteria. It includes contractor source inspection. Most Space Division programs have implemented some type of supplier surveillance. It is not required for Class S or substitute Class S parts since these parts receive government or government designated source inspection. The procedures for performing supplier surveillance are the same for subtier contractors as for the prime. However, the prime contractor has the additional management responsibility to designate representatives as necessary.

Recommendations

1. Prime contractors implement better flowdown of parts requirements.

    a. Define parts program early
    b. Assure maximum prime/sub cooperation
    c. Conduct tasks centrally to avoid duplication

2. Subcontractors become familiar with SD parts documents.

3. Primes and subs cooperate in coordinated procurement of parts.

4. Primes and subs purchase highest quality parts available.

5. SD document required/recommended flowdown of parts requirements.

6. Contractors/users send recommended improvements (in writing) to SD/AQT.

After evaluating the implementation of parts control programs on Space Division contracts, several recommendations are offered.

An important lesson learned is to define the parts program as early as possible. Some programs have defined most of the parts plan details by the contract start date. Centrally conducted tasks, e.g., supplier surveillance, coordinated procurement, and preparation of part specifications will reduce duplication of effort.

Becoming familiar with the requirements of Space Division parts documents before they are on contract should improve proposals. As Col VanMeter mentioned, it should prevent offerors from accepting efforts for which they aren't fully prepared, and enable a more timely implementation of the MIL Spec requirements.

Repeating the advantages of coordinated procurement, they include reduced parts documentation, better schedules, less inspection effort, and lower costs.

Purchasing the highest quality parts available is essential for achieving mission success.

Documenting recommendations and requirements of the better methods for flowing down the piece parts requirements has been considered. Also, preparing a seminar or training on the specific requirements of MIL-STDs 1546 and 1547. We would be willing to accept an action item for these efforts.

We have heard criticisms and comments on the Space Division documents and would like to receive some sound change proposals with supporting rationale and data.

CONTRACTING FOR GOODS AND SERVICES
A QUALITY PROBLEM NOW - THE FUTURE??
by

Charles R. Mercer
Director, Quality Assurance
McDonnell Douglas Electronics Company

Good afternoon ladies and gentlemen. I would like to welcome you to Session 2 of Workshop C, Subcontract Management - The Prime and Subcontractor's Viewpoint. I would like to make a few opening remarks relative to this general discussion as a way prefacing our activity this afternoon. I will try to make this short and to the point and at the same time put forth to you the issues as I see them at this point in time.

Why is this an appropriate discussion? --Well, in my opinion, neither the Government nor the contractors do a good job with their contract requirements flow down. Typical problems seen in today's subcontracting activity involve overspecification (most typical). This stems from a lack of understanding of the true requirements and a "CYA" attitude toward taking the time to actually analyze the proper flow down. On the other hand however, is a situation where, in fact, proper flow down of all the appropriate requirements is not accomplished. Both of these gross errors have a tendency to introduce down stream controversy and ultimately delays in delivery of conforming qualified hardware. When you add delays and conflicts together they spell only one thing - products cost too much.

A good question one might ask is; Who is to blame for this situation? Is it the Government? Is it Industry? Is it both? I believe the answer is that both entities share an equal responsibility for this situation.

Where did we go wrong? Typical difficulties are: reliance on boiler plate, not enough time to do it right (typically based on unrealistic schedule requirements), not enough technical talent used in the actual contractual requirements and, unfortunately, reliance upon using Mil-Specs called out in their entirety within the specification.

What is the impact of these mistakes? - - But, before I discuss that, I feel that all of you can somehow identify with the points I raised just a second ago. I know of no contract between the Government and the prime or the prime and his subcontractors that have not experienced, at least to some extent, difficulties related to the aforementioned mistakes. Getting back to the impact of these mistakes; the following are prime examples of real program impacts. 1. As I mentioned before, products and services cost more. 2. The delivery schedules are also harder to meet. This type of problem is typically exacerbated by delays in moving products through manufacturing due to specmanship by the contractors or the Government QA representative. 3. Last, but not least, as we contractors are well aware, delay in payments after the work is done is often caused by certain "procedure difficulties". At this point, a little history review is in order.

I would like to bring a contrast to your attention. This example is intended to have its shock value and it is not necessarily illustrative of what I think today's contracts should look like. However, I think it will be amusing and pertinent to our disucssions here today. We should consider that our predecessors, although considered to be non-technically oriented, may have had some good ideas. The example is a three page Signal Corps specification generated in 1907, which is purported to be the Wright Brothers initial contract. As I quickly flash these slides before you, I would like to call your attention to the sections I have marked; specifically on the first slide: Inspection -- The Government reserves the right to inspect any and all processes of manufacture. Obviously no special requirements were levied upon the contractor by this inspection clause.

On Slide number 2, item number 4, is an interesting concept that has been kicked around as a possible contractual incentive at numerous symposia in the past. Obviously, in 1907 the Government recognized the value of a quality incentive and included it as you can see in the specification. The last item that I wish to call your attention to is the

general requirements for how the machine should perform as opposed to exactly how it should be done. It is obvious that the requirement for "sufficient" simple construction and operation requirements such that an intelligent man could become proficient in its use within a reasonable length of time is really stating the requirements in general terms.

To further illustrate my point and to bring you forward in time, the next slide identifies a general requirement type specification generated to the Boeing Aircraft Company in 1936. In this specification for a multi-engine bomber, only the five general requirements noted defined what the Government had in mind. The results of these requirements and the contractors ingenuity in satisfying them, produced a rather significant airplane. I am speaking of Boeing Model 299, alias the B-17. It is also interesting to note that Model 299 flew eleven months after the contract was awarded.

I would now like to discuss the present situation, as I see it, with respect to contracting for goods and services. It is obvious that the Government has become increasingly aware of getting more for its' buck. One way of doing this is to streamline the contract activity. I feel that the latest developments in this area are interesting to review.

I will not attempt to read these examples to you from the slides; however, the fact that various agencies have revised these documents to detail a more intelligent way of doing business, is what I feel is significant. The first one, put out by the Office of Management and Budget (OMB) is Circular A-109. DoD has also been active in this area revising documentation such as the following: DoD Directive 5000.1, 5000.37, 4120.21 and 4155.1. All these documents have been revised to streamline the way DoD acquires its hardware and services.

The Air Force has also been looking into this area. I would like to call your attention to the "Quality Horizon Study" conducted by Col. Bernie Weiss. I have taken the liberty of using excerpts from his speech at the AIA/NSIA/QRAC Conference in Williamsburg, Virginia in October of 1979. This slide provides you with the background, but I would like to specifically comment on the findings related to contracts. The study concluded that the Air Force is not doing as well as their commercial counterparts in contracting for goods and services. This may indicate a change to more commercial like contracting activity on the part of the Air Force. Only time will tell. The second finding that I thought was interesting to see was the realization that Government effort is light on the front and heavy on performance verification. The study recommended that the Government effort be modified so as to put equal emphasis on front end and performance verification. These are obvious moves which could make the future better; but will it?? The future is hard to predict, but it seems to me that reasonable direction has been given from on high. The real question is: "Will the implementation of the DoD directive by the PCOs and CAOs, really pick up this thrust?"

From my point of view, the onus is on the Government to do a better job, but the contractors must share the responsibility to make it happen. Both contractors and Government must be responsible in their contracting activity. This involves taking the initiative to incorporate the concept of specification tailoring in order to get the most for the buck. Both should promote and insist upon a non-adversarial role by involved parties. And; lastly, the KISS principle should prevail - "Keep it simple stupid."

In summary, we have made a lot of mistakes in contracting and invoking contractual requirements. We should have learned something from these mistakes. It is obvious that we do not have to continue to make these mistakes ad nauseum. I believe the proper groundwork is laid and that the opportunity is available on each new contract to use common sense in contracting activity. Give consideration to not accepting anything less in your company contracting affairs than you would in your own personal contracting affairs. This approach will meet our mutual goal of more product for the buck.

Thank you for the opportunity to be co-chairman of this workshop and we will begin with our first panel speaker for the afternoon.

CONTRACTING FOR GOODS AND SERVICES
A QUALITY PROBLEM NOW - THE FUTURE??

PRESENTED BY

CHARLES R. MERCER

FOR

1980 CONFERENCE AND WORKSHOPS ON MISSION ASSURANCE

29 APRIL 1980

PAST

- WHY IS THIS AN APPROPRIATE TOPIC??
  - NEITHER GOVERNMENT NOR THE CONTRACTORS DO A GOOD JOB WITH CONTRACT REQUIREMENTS (CLAUSES)
    - OVER SPECIFY (MOST TYPICAL) CYA
    - UNDER SPECIFY
  - RESULT - THINGS COST TOO MUCH
- WHO IS TO BLAME FOR THIS SITUATION?
  - GOVERNMENT
  - INDUSTRY

- WHERE DO WE GO WRONG?
  - BOILER PLATE
  - NOT ENOUGH TIME TO DO IT RIGHT - UNREALISTIC SCHEDULES
  - NOT ENOUGH TECHNICAL TALENT USED IN CREATION OF THE CONTRACTUAL REQUIREMENTS
  - RELIANCE UPON MIL-SPECS (IN THEIR ENTIRETY) TO SPECIFY REQUIREMENTS
- WHAT IS THE IMPACT OF THESE STANDARD MISTAKES?
  - PRODUCTS AND SERVICES COST MORE
  - DELIVERY SCHEDULES ARE HARD TO MEET
  - DELAYS IN MOVING PRODUCTS THROUGH MANUFACTURING DUE TO SPECSMANSHIP BY THE CONTRACTORS QA OR THE GOVERNMENT QA REPRESENTATIVE
  - DELAYS IN PAYMENT AFTER WORK IS DONE CAUSED BY "PROCEDURAL DIFFICULTIES"

1936: AAF SPEC FOR A MULTI-ENGINE BOMBER

- BOMB LOAD
- CEILING
- SPEED/RANGE
- RUNWAY LENGTH FOR TAKEOFF
- CLIMB RATE

RESULT: BOEING MODEL 299 ALIAS THE B-17

NOTE: FIRST MODEL 299 FLEW IN ELEVEN MONTHS AFTER CONTRACT AWARD.

PRESENT

- o THE GOVERNMENT HAS BECOME INCREASINGLY AWARE OF THE PROBLEM OF GETTING MORE FOR ITS BUCK. ONE WAY OF DOING THIS IS TO STREAMLINE ITS CONTRACTING ACTIVITY. THE LATEST DEVELOPMENTS ARE INTERESTING TO REVIEW.
- o THE RE-THINKING STARTS AT THE HIGHEST LEVELS.

OFFICE OF MANAGEMENT AND BUDGETS (OMB) CIRCULAR A-109
GENERAL POLICY:
THE POLICIES OF THIS CIRCULAR ARE DESIGNED TO ASSURE THE EFFECTIVENESS AND EFFICIENCY OF THE PROCESS OF ACQUIRING MAJOR SYSTEMS. THEY ARE BASED ON THE GENERAL POLICY THAT FEDERAL AGENCIES, WHEN ACQUIRING MAJOR SYSTEMS WILL:

(A) EXPRESS NEEDS AND PROGRAM OBJECTIVES IN MISSION TERMS AND NOT EQUIPMENT TERMS TO ENCOURAGE INNOVATION AND COMPETITION IN CREATING, EXPLORING, AND DEVELOPING ALTERNATIVE DESIGN CONCEPTS.

(B) PLACE EMPHASIS ON THE INITIAL ACTIVITIES OF THE SYSTEM ACQUISITION PROCESS TO ALLOW COMPETITIVE EXPLORATION OF ALTERNATIVE SYSTEM DESIGN CONCEPTS IN RESPONSE TO MISSION TERMS.

- o *DOD DIRECTIVE 5000.1 - MAJOR SYSTEM ACQUISITION
  - o STRESSES FLEXIBILITY
  - o REQUIRES GREATER DEPENDENCE UPON MISSION REQUIREMENTS
- o DOD DIRECTIVE 5000.37 - ACQUISITION AND DISTRIBUTION OF COMMERCIAL PRODUCTS
  - o ACQUIRE OFF-THE-SHELF PRODUCTS
  - o ELIMINATE UNNECESSARY GOVERNMENT SPECIFICATIONS FOR COMMERCIAL PRODUCTS
  - o OPTIMIZE THE GOVERNMENT ADVANTAGE WHILE MINIMIZING THE ADMINISTRATIVE BURDEN
- o *DOD DIRECTIVE 4120.21 - APPLICATION OF SPECIFICATIONS, STANDARDS, AND RELATED DOCUMENTS IN THE ACQUISITION PROCESS
  - o AVOID BLANKET IMPOSITION OF SPECS, STANDARDS AND RELATED DOCUMENTS. TAILOR TO MEET PROGRAM REQUIREMENTS.
  - o CONTRACTUAL IMPOSITION SHALL BE LIMITED TO THOSE DOCUMENTS SPECIFICALLY CITED IN THE CONTRACT
  - o ALL OTHER DOCUMENTS INCORPORATED THRU REFERENCE WITHIN CITED DOCUMENTS SHALL BE CONSIDERED AS "GUIDANCE" OR "INFORMATION".

*IN COORDINATION WITH INDUSTRY

- o DOD DIRECTIVE 4155.1 - QUALITY PROGRAM
  - o EFFECTIVELY ASSURE THAT ONLY MINIMUM ESSENTIAL QUALITY AND RELATED REQUIREMENTS ARE SPECIFIED
  - o TAILOR CONTRACTUAL QUALITY REQUIREMENTS TO MEET THE NEEDS OF EACH ACQUISITION
- o MILITARY HANDBOOK - PROPOSED - DOD-HDBK-248A SUPERCEDING MIL-STD-248(AS) 1 APRIL 1977
- o QUALITY HORIZON STUDY - USAF, COL. "BERNIE" WEISS - EXCERPTS TAKEN FROM HIS SPEECH AT AIA/NSIA/QRAC CONFERENCE IN WILLIAMSBURG, VA., OCTOBER 1979
  - o BACKGROUND - 6 MONTHS STUDY
    - o COVERED COUNTRIES AROUND THE WORLD
    - o 66 COMPANIES AND GOVERNMENT AGENCIES VISITED
  - o MAJOR FINDINGS AS RELATED TO CONTRACTING
    - o AF NOT DOING AS WELL AS THEIR COMMERCIAL COUNTERPARTS IN CONTRACTING FOR GOODS AND SERVICES
    - o GOVERNMENT EFFORT IS LIGHT ON THE FRONT END AND HEAVY ON PERFORMANCE VERIFICATION - SHOULD BE A BALANCED EFFORT

THESE ARE OBVIOUSLY POSITIVE MOVES WHICH SHOULD MAKE THE FUTURE BETTER. BUT WILL IT??

FUTURE

- o REASONABLE DIRECTION HAS BEEN GIVEN FROM ON-HIGH, BUT WILL THE IMPLEMENTERS OF DOD DIRECTIVES, THE PCOs AND CAOs, REALLY JUMP ON THE BAND WAGON?
- o FROM MY POINT OF VIEW, THE ONUS IS UPON THE GOVERNMENT TO DO A BETTER JOB, BUT THE CONTRACTORS MUST SHARE THE RESPONSIBILITY TO "MAKE IT HAPPEN".
  - o CONTRACTORS AND GOVERNMENT MUST BE RESPONSIBLE
    - o REVIEW CONTRACTS WITH THE IDEA OF TAILORING TO GET THE MOST FOR THE BUCK
    - o NOT TAKE THE EASY WAY OUT AND ENVOKE COMPLETE SPECS
    - o COOPERATE ON A NON-ADVERSARIAL BASIS TO REACH THE GOAL OF AN OPTIMIZED CONTRACT
    - o THE KISS PRINCIPLE SHOULD PREVAIL - "KEEP IT SIMPLE STUPID".

- o SUMMARY:
  - o WE HAVE MADE A LOT OF MISTAKES IN CONTRACTING AND INVOKING CONTRACTUAL REQUIREMENTS
  - o WE DON'T HAVE TO CONTINUE TO MAKE THE SAME MISTAKES AD NAUSEUM
  - o GROUNDWORK IS LAID
  - o OPPORTUNITY IS AVAILABLE ON EACH NEW CONTRACT
  - o UTILIZE THE TOOLS - COMMON SENSE - AVAILABLE
  - o THE PEOPLE WHO MAKE AND ENFORCE THE CONTRACTS ARE THE KEY TO THIS EFFORT. DON'T ACCEPT IN YOUR CONTRACT EFFORT ANYTHING LESS THAN YOU WOULD IN YOUR PERSONAL CONTRACT AFFAIRS. THIS APPROACH WILL MEET OUR MUTUAL GOAL OF MORE PRODUCT FOR THE BUCK.

Flow-Down of Quality Requirements to Semiconductor/Microelectronic Suppliers

Conrad H. Zierdt, Jr.
Bell Telephone Laboratories
Allentown, Pa.

Chairman, JEDEC JC-13, Committee on Government Liaison

By What Authority?

DESC - MIL-S-19500 Appendix D
MIL-M-38510 Appendix A

These are detailed and specific for discrete devices and microcircuits, respectively.

DCASR - and Customers MIL-Q-9858A

Para. 1.3 "The [Quality] program shall include an effective control of purchased materials and subcontracted work."

Section 5 "The effectiveness and integrity of the control of quality by his suppliers shall be assessed and reviewed by the contractor at intervals consistent with the complexity and quantity of product."

Quality {Systems / Program / Control / Assurance} Surveys

Parkinson's Law in Action

via

MIL-Q-9858

and The Establishment

Old, Large, Broad-Product-Line Company.

Data from 2/3 of total plants available for survey; year-to-date Oct. 1977:

Total 110 audits and surveys.
1300 company man-hours expended.
1.5-2 visitor man-days (in-plant) per visit

Comment: 40% of visits superficial or superfluous

Old, Medium, Fairly-Broad Product Line Company

Average for past 2 years, one location:

17 visits per year
$10,000/yr. company expenditure
2 visitors, 2 days per visit

Comment: Visits begin October and taper off in April at California location.

Old, Large, Broad-Product-Line Company

Visits by prime/sub-contractors under MIL-Q-9858A only:

1973	74	75	76	77 YTD
21	11	8	12	13

5-6 company man-hours per visit
2 visitors, 1 day typical.

Comment: Both pre (when bidding) and post (after contract award) visits seem unnecessary.

NEW, SMALL, RESTRICTED-PRODUCT-LINE COMPANY

DATA FOR FIRST NINE MONTHS OF 1977

67 VISITS
127 VISITORS
1356 COMPANY MAN-HOURS DURING VISITS
(NO FIGURE FOR PREPARATION TIME)

COMMENTS: 1) PROBABLY FEWER VISITS IF NOT LOCATED IN SILICON VALLEY.

2) VISITORS INCLUDE MOST AEROSPACE CONTRACTORS.

WHO SURVEYS ?

DESC-EQ - 1 VISIT PER YEAR PER PRODUCT LINE
FULL-TIME ENGINEERING PERSONNEL

DCASR - SPORADIC
QUALIFICATIONS VARY WIDELY.

CUSTOMER REPS. - GENERALLY 1 VISIT PER YEAR
QUALIFICATIONS VARY WIDELY.

COMMON BELIEFS/POSTURES:

KNOWN QUALITY FACTORS BETTER THAN DEVICE MANUFACTURER.

ARE BETTER MOTIVATED.

SUMMARY OF STATISTICS

FOUR (4) VISITS WOULD HAVE BEEN AS EFFECTIVE AS WERE TWO HUNDRED SEVEN (207) IN 3/4 OF 1977.

CONSERVATIVELY, FOR 203 EXCESS SURVEYS:

TRAVEL @$500/TRIP	101,500
CONTRACTOR TIME @ 2 MAN-DAYS/TRIP.	126,875
SUPPLIER TIME @ 4 MAN-DAYS/TRIP	253,750
AVOIDABLE COST =	$482,125

WHAT'S THE PROBLEM?

TOO MANY VISITS:
- EAT SUPPLIER QUALITY-ASSURANCE PEOPLE'S TIME
- DIVERT MANUFACTURING WORK FORCE
- CAUSE UNNECESSARY COST TO THE GOVERNMENT:
  - DIRECTLY, FOR TRAVEL.
  - INDIRECTLY, AS COST TO DEVICE SUPPLIERS

TOO MANY EXPERTS:
- CONVEY TOO MANY PRESCRIPTIONS FOR INSTANT RELIABILITY.
- ASK FOR FAR MORE THAN SPECIFICATIONS REQUIRE.

PARKINSON PREVAILS

RATE OF VISITATION HAS NOT BEEN NOTICEABLY REDUCED, SINCE 1965 OR 1978.

IMPLICATIONS:

THE ACTIVITY CONTINUES AT A LEVEL CONSISTENT WITH THE MONEY AVAILABLE AND THE ESTABLISHED FUNCTIONAL GROUPS/PATTERNS IN EQUIPMENT CONTRACTORS' HOUSES.

CASE IS FOR GOD, MOTHERHOOD, AND APPLE PIE, BUT NOT ACTION.

RECOMMENDATIONS

1) CHANGE MIL-Q-9858 BY CUTTING OUT THE FLOW-DOWN (TO PART LEVEL) PROVISIONS, WHEN PARTS SPECIFICATIONS INCLUDE APPROPRIATE REQUIREMENTS.

2) STOP PAYING FOR EQUIPMENT-CONTRACTOR SURVEYS, UNDER THE SAME CIRCUMSTANCES.

WHAT'S BEING DONE?

1978 MEMO - LESTER FOX, DIRECTOR, DMSSO TO MR. JOHN MITTINO, DEPUTY DIRECTOR, OUSD/R&E

"PRIME CONTRACTORS ARE NOT MAKING EFFECTIVE USE OF THE SUPPLIERS' OBJECTIVE EVIDENCE OF QUALITY AND THE CONTRACTORS' OWN RECEIVING INSPECTION TO REDUCE THE NUMBER OF ON-SITE AUDITS. FURTHER THERE IS NO "RECIPROCITY" AMONG THE SERVICES AND PRIMES IN AUDITS ALREADY CONDUCTED WHERE A DETERMINATION OF SUITABILITY HAS BEEN MADE."

1978 MEMO - CAPT. C. H. LAMB, DLA-QEL TO STAFF DIRECTOR FOR QA, OUSD R&E (SOS)
"THE RESULTANT SITUATION IS A STEADY STREAM OF VISITORS TO THE MORE IMPORTANT COMPONENT SUPPLIERS.

A FIRST STEP IN THE ALLEVIATION OF THIS SITUATION WOULD BE TO DIRECT THE SPECIFICATION PREPARING ACTIVITY TO CONSIDER A CHANGE TO THE PERTINENT SPECIFICATION PARAGRAPHS. THE CHANGE SHOULD NOT AFFECT THE BASIC PHILOSOPHY OF MIL-Q-9858A. IT SHOULD ENCOURAGE JOINT SURVEYS BY INDUSTRY AND RECIPROCITY RELATIVE TO ACCEPTABLE AUDIT OR SURVEY RESULTS."

1964 - 65 - CORRESPONDENCE BETWEEN SAME GOVERNMENT FUNCTIONS AND EIA, IN IDENTICAL VEIN.

CASE = COORDINATING AGENCY FOR SUPPLIER EVALUATION
AN ASSOCIATION OF AEROSPACE AND NUCLEAR INDUSTRY COMPANIES - FURNISHES(ED) A REGISTER OF QUALITY-CONTROL EVALUATED SUPPLIERS.

PUBLIC LAW 95-507
by

Sewell T. Kauffman, Manager -
Small Business Utilization
McDonnell Douglas Corporation
St. Louis, Missouri

I was asked to discuss Public Law 95-507 and its impact upon contractors--but I'm sure that I'm going to learn far more from you than you learn from me.

Any procurement personnel of any large company negotiating a contract with the Federal Government exceeding $500,000 (or $1,000,000 for construction), since the first of the year, will have gotten up to his eyeballs in correspondence concerning 95-507. Dale Church, Deputy Under Secretary of Defense, said that there is "absolute chaos" in the implementation, with goals and means of implementation which are turning out to be "meaningless."

Its not that the law itself is so complicated. It's the fact that every Federal agency has made its own interpretation of the law and expanded on its requirements. To top this off, the Office of Federal Procurement Policy has dragged its feet in issuing its implementing instructions. Therefore, nobody is in a position to tell the many procurement contracting officers that they are asking for too much.

Let's look at the Law and see what is required--just six points:

1. Percentage Goals;
2. The name of the Subcontract Administrator and his duties.
3. A description of the efforts we'll take to assure that Small & Disadvantaged firms have an equitable opportunity to compete.
4. Assurances we'll flow-down the clause.
5. Assurances we'll submit periodic reports and cooperate in any studies; and
6. A recitation of the types of records we'll keep.

Now look at what's required:

1. Percentage Goals - Who's kidding. The Air Force wants, in addition to percentages, the total dollar value of planned subcontracting, total to small, and total to disadvantaged firms. They want a description of the principal product and service areas to be subcontracted and an identification of those areas where small and disadvantaged firms will be used. The Air Force wants the contracting officer to be furnished the names and locations of the principal small and disadvantaged subcontractors including the type of product or service and dollar value thereof to be awarded to each principal subcontractor. The Air Force wants the method used in developing the proposed subcontracting goals. For example--Did we use company source lists, PASS, NMPC, etc. And lastly, they want to know the method used in determining indirect and overhead costs to be allocated to that particular acquisition.

This is all included under the Public Law 95-507 innocent heading titled "Percentage Goals."

2. Name of the individual--This is not too bad. The Air Force suggests that the individual be placed in the organizational structure for reporting directly to the chief executive or vice president.

3. A description of the efforts to assure small and disadvantaged firms' participation--In this we must include company-wide policy statements, proof of management interest and involvement, "feedback" briefings, corporate and divisional goals, etc. We must establish and describe personnel training and motivation programs. We must describe our special assistance program to help small and disadvantaged firms. How are they considered in our Make-or-Buy plans. And we must describe our efforts to participate in counselling activities sponsored by business and government groups.

4. Clause Flow Down--Not too bad. We have to acknowledge that we have the obligation to flow-down the clause. However, this turns out to be a real sleeper. The Navy and OFPP stipulate that the Prime Contractor is responsible for monitoring compliance by his subcontractors. The NAVPRO's responsi-

bility in this area is to see that the Prime is taking action to see that the subcontractor is complying with the provisions of the subcontracting plan. OFPP believes that Prime Contractors should not only flow down, monitor and obtain statistical data from subcontractors, but also must include in their plans the management techniques that will be employed to accomplish this task. I might add that in 1979 McDonnell Douglas had 699 purchase orders, not to mention the innumerable modifications and change orders involved, which exceeded $500,000.

5. Reports and studies. On the surface this was left pretty much alone. We have to include in the Plan assurance that we will make the required reports and cooperate in any studies. Much hinges on the issuance of OFPP's implementing instruction regarding reports. They have proposed the use of a Federal Quarterly Individual Subcontracting Report as well as a Federal Quarterly Summary Subcontracting Report. The data required includes awards to Small and Large Businesses, Disadvantaged Businesses, Women-Owned Businesses, Labor Surplus Area Awards, Awards to Non-Profit and Foreign Subcontractors; number of active contracts having small business goals, number with work completed, number completed which met small business goals, etc.

6. And last but not least, we come to Records--The Public Law wants a recitation of the types, the establishment of source lists for small and disadvantaged, and a means to identify our efforts to award subcontracts to such small business concerns.

You now have a fairly good picture of the original Public Law requirements and what has happened in the implementation of this law. For the first two months of this year, our subcontracting plans were short, concise and easily understood. Or, so we thought. For the first two months not a one was approved. We then began to wax elequent, became more descriptive and verbose. The bigger the plan, the greater chance we had of its acceptance. We have now reached that level of understanding with our usual customers wherein our communications are good. Our plans are being accepted with few exceptions. The administration of 95-507 is causing us to add an estimated ten persons to our various MDC small business offices. And we still don't know how many more will be required when we get into the tracking of all these plans, coordinating studies and making reports. I have not included the requirements imposed on our Contracts Department where each plan has to be negotiated with the customer. Since January of this year, McDonnell Aircraft Company has submitted over 50 subcontracting plans. In the few cases wherein we stated no plan was required because no subcontracting possibilities existed, we merely started a war of words because the PCO felt he should have a plan.

In spite of all the problems involved in implementing this law, we are reaching an understandable and workable relationship with the PCO's. You can compare this with a shotgun wedding. It's starting to develop into a marriage of convenience--and, who knows, some day it might become a love match.

OVER-THE-SHOULDER AUDITS

Dave Arnott

SENIOR QUALITY CONTROL ENGINEER
GENERAL DYNAMICS CONVAIR

Quality Assurance Auditing is not new but prior to the 1960's it was seldom employed. During the 60's, Convair, because of their Quality reputation on the Atlas missile, was put under contract to provide an audit program to indemnify the Defense Department against poor process and quality control. The program reported directly to Robert MacNamara, Secretary of Defense. During the five years of its existence, with a crew of eight, it proved to be highly rewarding to the Defense Department.

Government agencies analyzed the results and concluded that economies were to be had without undue risk. Accordingly, they reduced their hardware inspection activity in favor of comprehensive audits.

Through the Defense Department Audit Program, Convair became the grandfather of the audit system. It was the result of the NASA Gaberiel-Dey Audit in 1971 of the Atlas Centaur program that Convair was funded for a full scale quality audit program. This was a joint effort by NASA and SAMSO.

The purpose of an audit program is to verify that the Management Procedures, the Product Design Requirements and the Production processes are being conducted to the requirements. The audit provides visibility to management and ascertains that the program plan adequately implements the customer requirements. The placement of the audit function within the organization is very important. It must report on a staff level in order not to be influenced by the functions being audited. Convair's Quality Assurance Director, our highest authority in Quality, reports to the General Manager. The Quality Assurance Audit Group reports directly to him. This assures the Auditors can carry out the audit objectives without interference from subtier supervision. What are these objectives? Foremost, of course, is to insure that the customer's requirements are fully met. The first customer requirement is to have the contractor conduct self audits to verify his operations and prevent the production of nonconforming supplies. The audit is also beneficial to management by minimizing surprises and establishing visibility into how well the total operation is performing. It further establishes customer confidence, minimizing the necessity for the customer, to conduct audits which are time consuming and costly to the customer and to the contractor. There is a further objective of determining that the contractor is complying with contractual requirements and has adequate procedures or work instructions to enable conformance. An audit also evaluates the product through spot reinspection to measure the results of the entire Quality System. Last but not least, the effectiveness of the corrective action system must be assessed to determine its ability to prevent the same discrepancies from happening twice. We do this by conducting specific types of audits both in our house and at our suppliers.

Audits can only be conducted in an effective manner when the auditor is provided adequate time to prepare a comprehensive audit plan. He must expend considerable time in determining the requirements of the "Contract" -- what does the contract say? He must study in detail the engineering requirements and the specifications imposed therein. Further effort must be expended on a thorough analysis of the contractor's internal procedures and quality disciplines to see that all requirements are compatible. Work instructions must also be reviewed to determine if they convey the information, in proper sequence to enable the worker to carry out the job. Since the contractor's internal auditors are familiar with the contractor's procedures and organization, this task can be done much

AD-A152 733 PROCEEDINGS OF INDUSTRY/SPACE DIVISION/NASA CONFERENCE AND WORKSHOPS ON M.. (U) SPACE DIV LOS ANGELES AFS CA 02 MAY 80 3/9

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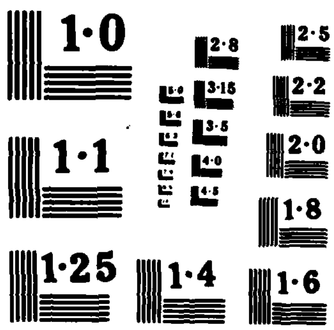
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more efficiently than it could be accomplished by customer auditors unfamiliar with the contractor's systems and organization. Therefore, the Over-The-Shoulder Audit concept becomes a very cost effective method for the customer.

Product reinspection audits tell us how we are doing. It also is a measure of individual inspectors. Keeps them on their toes and enables supervision to correct and reinstruct where necessary. At the time of reinspection audits, planning is reviewed as well as the engineering drawing. We see that all engineering requirements are reflected in the planning and that engineering is complete as to calling out the contractually imposed specifications. A review is made of previous discrepancies to evaluate the effectiveness of corrective actions. If a vendor part is involved, a review of receiving inspection documentation is made to determine that we have the proper certifications and have completed quality engineering requirements.

Processing is another type of audit. We, like other organizations, have experts on processing. Documents are written that impose specific disciplines on the way things are processed. We must assure that the recipe is followed in detail to guarantee that the product is right. Process certification is an important ingredient. Unless you know that the equipment, solutions, temperature, working zones of a heat treat oven are capable of meeting specification requirements, you are lost. You must also know that the people operating this equipment have a thorough understanding of the disciplines imposed. The auditor, therefore, checks process certification and personnel certification. The recipe must be checked to determine, for instance, that the chromium plating is not accomplished prior to magnetic inspection. This situation would nullify the inspection check. On top of all this, the auditor keeps his eye peeled for safety items for safety is everyone's business.

Another phase of auditing is the policing of required tests. Here we must assure the company that the test procedure incorporates all those things that were determined to be of value by Engineering. We must also concern ourselves with the people performing the test. We do not want the type of employee who conforms to the trite statement that "yesterday I could not spell engineer, but today I are one." The auditor, therefore, checks to see that the personnel are certified by Quality Engineering. It is obvious that if we have a specific pressure requirement we would want to know that the pressure gage being used reflects the exact pressure. To this end, Calibration becomes a most important ingredient and must be observed to assure accuracy. The auditors are only in the area periodically and at best, can only sample the performance. The back bone of testing is the inspector on the job. The auditor is, therefore, very concerned that inspection is following the test and that the inspector knows his business. Documentation of test results is most important. Should something go wrong with the item under test, it is necessary to know the complete details of the test. Often we find such important things as time, temperature and pressure have been omitted on the data sheets. We check for this. Again, audit must be sensitive to all safety requirements.

A satisfactory cake cannot be baked without a good recipe. In our business, work instructions (planning) is the recipe. Planning must include the drawings and specifications requirements, procedures to be used, the quality requirements to be met and the step-by-step approach to each event. Our auditors on a random basis audit a number of pages of planning to determine if all of the disciplines are being met.

All Quality programs must have a road map. This is called the Quality Program Plan. Because of the large volume of paperwork, there is often a hole in the basket. It is the responsibility of the auditor to identify these holes. Therefore, the program plan is audited to determine if the plan adequately implements the procedures necessary to

produce a quality product in compliance with design requirements. Once this is established, the audit must concern itself with the conformance to procedures. To this end, a comprehensive audit is conducted of systems and procedures. In our company this is an audit of our Division Standard Practices and their integration with the various manufacturing procedures. This is to assure that program plans, manufacturing instructions and quality directives are in synchronization resulting in a uniform system.

Often times the audit function is called upon for special audits. These may be requested by management or the customer. A case in point was an unexplained rise in the rejection rate of Convair's machine shop. Both the customer and management commissioned the audit function to go in and try to determine the causes. Problems were identified as lack of machine capability, poor communication between worker and supervision, lax inspection techniques, tooling problems and shop lay out. There was a significant pay off for a two week effort by one auditor. We have initiated start centers, re-oriented inspection, removed paper loads from shop foreman and vastly improved communication. This is called corrective action - it pays off in reduced rejections and increased efficiency.

Supplier audits, while generally the same as internal audits, do have significant differences. Of prime import is the communication between the purchasing department and the supplier. This is best tested by supplier visits. Does he have all the information that he needs to produce a Quality Product? Often the answer is no. Corrective action is initiated by the auditor. It probably should have been taken by Source Inspection so included in the audit is an evaluation of the effectiveness of the source inspector. A minor amount of product reinspection is performed during the audit to determine two things -- does the supplier conform to requirements and has our own Quality Engineering identified all of the Quality requirements? If not, they are reported in the audit and a Supplier Action Request (SAR) is issued to the purchasing department as well as an Action Request (QA) to the manager of Outside Procurement Inspection. These are very important facets to supplier audits. Does he have a Quality system responsive to imposed requirements, how does he control his critical processes and does he have a calibration system which is effective in guaranteeing uniform acceptability of the product traceable to the National Bureau of Standards to name a few.

Auditors cannot accomplish all of the desired results without a lot of pre-audit preparation. You can't send an auditor to a supplier to audit off the top of his head. Accordingly, we have an organized Pre-Audit Plan which is imposed on the auditor. Such things as purchasing requirements, design data, previous known problem areas and so forth must be incorporated in the Audit Plan. Aligned with these constraints is the source of information. The auditor must compile this information prior to scheduling the audit thus assuring that he knows what he is looking for when he gets on board.

We have determined the types of audits and it is to be anticipated that some unsatisfactory findings will result. How are they fed back for action? We use a serialized Quality Assurance Report categorized as an Action Request (AR). In the case of vendors, it is a Supplier Action Request (SAR). It is directed to responsible management; it states the problem and it demands timely action with a space provided for an explanation of the action taken. These are logged in the audit group and follow up is made. Where action is not prompt, a "do better" slip is issued. If action is still not forthcoming, it is brought to the attention of successively higher management for decision. When the AR or SAR is returned to the auditor, the answer is analyzed. If not satisfactory, conferences are called for esolution.

All audit reports are issued with a distinctive cover sheet. As an attention getter, it is on colored paper so that it does not get mixed

with routine memos on the recipient's desk. The audit group files a copy and when all actions are complete and satisfactory, the auditor applies his audit stamp with the word "closed" and the audit is filed for future reference and possible review by the customer. To this end Convair maintains an open book to the customer and seeks his review.

To keep management and the customer advised, a monthly summary is published of all activity conducted during the month. It portrays the number and types of audits, the percent non-conformance for the month, and the percent non-conformance year to date. Also included is a goal which is developed yearly based on past performance and by conference with the producing departments.

Our NASA, AF, Navy and Commercial customers have audit requirements included in their contractual documents. Notable is NASA document NHB5300.4 which in paragraph 1B205 imposes the responsibility upon the contractor to conduct internal audits with an independent team of specialists. Customer administrative documents impose upon them the responsibility of auditing the contractor. Most customers satisfy this requirement by conducting "over the shoulder" audits. This audit is conducted in conjunction with the contractors on going audit activity.

Previously our customers dispatched a team to our facility several times a year and with multiple customers this resulted in considerable disruption in normal activity and was in effect time consuming for the customer and the contractor. With the "over-the-shoulder" concept the efficiency of both customer and contractor has been measurably improved. The customer reviews the schedule of audits and decides what he wishes to participate in on a timely basis. He has the advantage of prepared audit plans, the results of prior audits and access to failure history. He functions as an actual member of the contractor's audit team still maintaining an independent judicial attitude. His independent findings are entered into the audit discrepancy report and action requests are generated in the normal fashion. He conducts an audit debriefing to discuss his opinion of how the audit was conducted and to present any significant findings he has gleaned over and above those of the contractor's audit personnel. The contractor's audit team follows up on corrective actions and is obligated to report to the customer. The customer has the additional option of doing two things. He can request special audits in which he may or may not participate, or he can bring in his own audit team and conduct an audit independent of the contractor.

Where is the pay off? There are definite benefits to over-the-shoulder audits.

There are several significant factors worth your attention. The review of Convair's previous audits and adequacy of the corrective action taken; the free unannounced area of participation; the review of the contemplated audit plan; the establishment of findings with attendant planned corrective action and last but not least, the helpful information imparted to Convair management in the debriefing which enables us to be more sensitive to customer desires.

- It is a cost effective way for the customer to evaluate the Contractor's Quality.
- It gives him the advantage of utilizing trained contractor personnel-seeing eye dogs as it were.
- It results in increased sensitivity to customer requirements for product quality, reliability and cost reduction.
- It satisfies the customer's self imposed Policy Directives for Contractor audits in a most economical fashion.
- The audits detect and report system deficiencies to management.
- Producers and Inspectors are more attentive to product quality.
- Timely detection of product deficiencies.

- Cost reduction by elimination of repetitive rejections.

We have seen that the technique of auditing for the control of Quality is not an entirely new adventure. It has, however, come into prominence in recent times as a management technique leading to a higher level of quality. It is most effective only when the audit reports to the highest level of management and is devoid of productive pressures.

Specific types of audits tailored to the demands of the product must be utilized such as product reinspection, process audits, test audits, calibration, system and procedures and audits of specific problem areas which have been identified. It must not be confined to in-house activity, but must also encompass suppliers and their sources.

It is very important that audits be carefully planned using audit plans established as a result of research of design and system requirements.

Participation by the customer in over-the-shoulder audits should be encouraged for it is cost effective and adds to the discipline when conducted in an open and fair cooperative manner. The success of the program is vested in management support, comprehensive and objective audit reporting with an adequate system of corrective action response and close out.

Our customers believe that we have one of the best audit programs in the industry and are completely satisfied in the over-the-shoulder audit concept. The attached letter from one of our customers is witness to this fact.

Space Administration

John F. Kennedy Space Center
Kennedy Space Center, Florida
32899

Reply to Attn of: SF-PRA-2

General Dynamics Corporation
Convair Aerospace Division
Attn: Mr. S. B. Chamberlain
LVP Assurance Manager
Dept 950-0
P.O. Box 1128
San Diego, CA 92112

Subject: GD/C Quality Assurance Audit of ETR Operations

In December 1976 and twice in 1977, personnel from KSC Quality Assurance Survey Branch participated in GD/C audits as observers in Over-the-Shoulder audit approach. These thorough and comprehensive audits and audit reports, along with the audit report review by the Chief of KSC Expendable Vehicle Quality Assurance Office, Mr. G.C. Mayer, satisfactorily meets all the requirements of KSC yearly survey schedule. With such a proficient, competent audit, it is possible to further cost savings. Therefore, personnel from my office will no longer participate in these audits or request GD/C audit reports. GD/C audits and the review made by Mr. Mayer, as previously stated, meet KSC yearly survey schedule requirements. If there are any quality assurance areas that require detailed scrutiny by GD/C audit team, I will get in touch with you directly or through Mr. Mayer.

I commend GD/C Quality Assurance Audit Office for a job well done.

John R. Atkins
John R. Atkins
Acting Chief,
Product Assurance Office

PRIME CONTRACTOR FLOW DOWN REQUIREMENTS

Louis R. Criez
Subcontracts Manager
Space Transportation Systems
Boeing Aerospace Company

As you can see from the topics of discussion in this conference, mission assurance requirements and activities are found in almost every aspect of our business. The pressures of schedules, budgets, practicality, experience, ability to adapt to new ideas and methods and more, all weigh heavily on the outcome of our efforts and the success of a particular program. I would like to discuss this subject with you as seen from the subcontracting function. I will review the prime contract flow down requirements to the subcontractor, how this is accomplished and then go over a few of the major problems we have encountered over the past years which are related to mission assurance. I would hope to leave you with a few thoughts for further discussion in this workshop and perhaps an idea or two on how things can be improved.

Where do the Requirements Come From

The basic derivation of requirements has not changed much over the years. As you might expect, the customer's request for quotation is the repository of his requirements. The prime contractor extracts these requirements, interprets them through discussions with the customer, adds any company requirements which are necessary to accomplish the task and flows the requirement to the subcontractor through the subcontract request for proposal. The requirements are then interpreted by the subcontractor, discussed with the prime contractor and used as the basis for the subcontract proposal. I have selected some of the flow down requirements from a high reliability program for your information. The right hand column provides a comparison to a high reliability commercial program. You can see there are many controls. This discussion will highlight the parts materials and process requirements. Changes occur during prime contract negotiations and interpretations are refined as work begins and customer's desires become more definitive.

So, program requirements come from . . .

a. Request for Quotation

b. Prime Contractor Requirements

c. Various Communications with the Customer

d. Definitized Prime Contract

e. Government Interpretation of Definitized Prime Contract

What are These Requirements

The contract requirements can be put into three groupings, which are:

a. Legal - This group is composed of items such as Buy American Act, Rights in Data, Affirmative Action, Defense Acquisition Regulations and so on. Boiler plate type things.

b. Technical - Consisting of the Military Specifications, Design Requirements, Reliability, and so forth.

c. Administration and Management - Which include items like Cost Reporting, Work Breakdown Structure, Schedules, and Data Requirements.

System effectiveness requirements are included in the technical and management groups.

Now How are These Reflected in Subcontracts

The requirements are given to the subcontractor in the Statement of Work, the Terms and Conditions and the Procurement Specification. The Procurement Specification is called by many names. It is the document that details the design and test requirements. Now you have a general picture of what requirements are, where they come from and how they appear in a subcontract. It is all clear and straightforward, but as you can imagine, this is often not the case.

How Does This All Work

A prime contract having significant subcontracts usually represents a task which is relatively well known to the interested subcontractors. Special studies,

procurement cycle conceptual phases, meetings, etc. precede subcontract proposal activity and awards. Through this type of activity, a general understanding of the requirements emerges from which many assumptions about requirements can be made.

I will point out a few of the major problems and then discuss them in more detail later.

The first significant problem related to assumptions is that customer requirements are not available when needed. The next, as I see things, is that new requirements are seldom definitized and that Government interpretations of these requirements are not adequately planned for. The next is that different or unusual application of specific military standards and specifications is generally misunderstood. The tree of reference documents has become so complex and interwoven that time does not allow adequate review and understanding. Finally, is the perennial problem resulting from the preceding items; the cost estimates are reflective of the assumptions, understandings and misunderstandings which may or may not be responsive to the task as envisioned by the customer. Now, let me go a little deeper into these problems with requirements flow down. The first problem mentioned was, customer requirements not available when needed. Subcontractor pricing must precede prime contractor pricing and the subcontractor needs no less time to prepare his proposal than the prime contractor.

To provide this time, subcontractor activities begin very early and it has consistently been my experience that this activity was started substantially ahead of receipt of the customer RFP. The prime contractor establishes the flowdown based on the best information he has . . . assumptions are made. Granted, there is information on which to base the assumptions, but the only acceptable way of going is to have the customer requirement in time to use them for quoting the job.

The next problem mentioned was that new requirements were seldom understood (definitized) and that government interpretation of these new requirements were seldom planned for. I am not saying that new requirements are totally misunderstood. What I mean is that the timing from receipt of a requirement or the determination that there is, in fact, a requirement, and what the customer intends, and the subcontractor's proposal is too short to allow adequate discussion and understanding. In the proposal rush, unanswered questions are handled inadequately. In many cases the requirements become definitized during the process of trying to do the work. Pricing and schedule agreements are based on assumptions, interpretations and understandings that may or may not be correct.

Since this is such a significant area, I will go into more detail with an example. In recent experience, we were required to comply with SAMSO-STD-73-2C "Electronic Parts, Materials and Processes for Space and Missile Applications, Standard Control Program for." We at Boeing were familiar with the document as were the major subcontractors. This familiarity resulted in the following expectations:

a. Compliant specification could be derived by modifying existing specifications.

b. Technical problems could be resolved by deviations and waivers to 73-2C or to the approved parts specifications. (Didn't really believe the customer would enforce the requirements since waivers and deviations were readily granted on previous programs).

c. 73-2C parts would be available when needed.

d. Budgets predictions at the prime level and subcontractor level would be adequate.

None of these expectations were realized. Preparation of parts specifications and obtaining customer approval was a massive effort far exceeding budgets. Approval cycles for parts specifications took many months and some over a year. Negotiation of approved specifications with the parts sources took longer than expected and lead times for 73-2C parts did not support program schedules. Parts suppliers found the 73-2C business to be impacting other more profitable business and schedules

deteriorated further. Substitute parts were required to support hardware fabrication schedules. The customer was unwilling to deviate from their interpretation of the requirements and on matters of technical interpretation, consistently required the course of action which had greatest impact on costs and schedules. The basic prime and subcontractor assumptions missed the reality of the situation and specification preparation and approval, parts costs, parts expediting, substitute parts and other activities to obtain approved parts to support the program devastated budgets and program schedules. Another consideration is that compliance with this type requirement is generally beyond the capability of small/disadvantaged business concerns.

Different or unusual application of specific standards and specifications are generally misunderstood. During the rush of proposal preparation, referenced compliance documents can be and are overlooked. This can best be demonstrated by another example from recent experience. MIL-P-28809 "Printed Wiring Assemblies" is a specification called out by MIL-STD-454 which is in turned called out by SAMSO-STD-73-2C. Since the subcontracted items were to be qualified to MIL-1540, qualifying the printed wiring assemblies to MIL-P-28809 was assumed not to be required, when in fact, it was, and there was no money budgeted for the task.

From this discussion thus far, some of the difficulties in preparing a responsive proposal should be apparent. The problems discussed relate particularly to high reliability programs and the impact is most clearly seen in the final problem mentioned. That is, the cost estimates and schedule commitments reflect understandings/misunderstandings. Simply stated, we have found that efforts to keep costs down on high reliability programs enhance the probability of inadequate cost and schedule estimates. No one wants to pay the price. There is no practical relationship between the costs of a very high reliability program and the usual mil-spec type program and yet the comparisons are made with resultant inadequate budgets.

I have exposed you to a few high points of this complex business from the viewpoint of subcontract management at the prime contractor level. Suggestions to minimize the impact of system effectiveness requirements are:

1. Standardize requirements; i.e., fix mil-specs rather than invent new ones.
2. Identify the requirements early and clearly.
3. Conduct a bidders briefing with the customer and all prime and subcontract bidders present to outline and explain any new and unusual requirements. Convince the bidders that this is really what is required and then be willing to pay the price.
4. Place a customer 73-2C administrator on site in the prime contractor's plant to handle parts, materials and processes problems in real time.

This is a brief look at the requirement flow down situation. Now let's look at the recipient of these requirements, the subcontractor, and his problems in producing hardware while meeting the requirements.

MISSION ASSURANCE CONFERENCE

SUBCONTRACT MANAGEMENT

REQUIREMENTS FLOW DOWN

DERIVATION:

- REQUEST FOR QUOTATION
- PRIME CONTRACTOR REQUIREMENTS
- COMMUNICATIONS WITH CUSTOMER
- DEFINITIZED PRIME CONTRACT
- CUSTOMER INTERPRETATION OF DEFINITIZED PRIME CONTRACT

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SUBCONTRACT MANAGEMENT

REQUIREMENTS FLOW DOWN

GROUPINGS:

- LEGAL
- TECHNICAL
- ADMINISTRATION & MANAGEMENT

MISSION ASSURANCE CONFERENCE
SUBCONTRACT MANAGEMENT

REQUIREMENTS FLOW DOWN PROBLEMS:

- CUSTOMER REQUIREMENTS NOT AVAILABLE WHEN NEEDED
- NEW REQUIREMENTS SELDOM DEFINITIZED
  GOVERNMENT INTERPRETATIONS NOT ADEQUATELY PLANNED FOR
- DIFFERENT OR UNUSUAL APPLICATION OF SPECIFIC MILITARY STANDARDS & SPECIFICATIONS MISUNDERSTOOD
- COST ESTIMATES & SCHEDULE COMMITMENTS REFLECT ASSUMPTIONS AND MISUNDERSTANDINGS

TYPICAL REQUIREMENTS IMPOSED ON SUBCONTRACTORS

FLOW DOWN REQUIREMENTS (A/F PARTIAL LIST)	REQUIREMENTS FOR COMMERCIAL SUBCONTRACTORS (AIRPLANE)
CONFIGURATION MANAGEMENT PLAN	CONFIGURATION CONTROL
PRODUCTION PLAN	
DESIGN TO COST	
COST/SCHEDULE REPORT	PROGRAM PLAN & STATUS
CONTAMINATION CONTROL PLAN	
EMC CONTROL PLAN	
SINGLE POINT FAILURE LIST	
RELIABILITY PROGRAM REPORT	
REPAIR PARTS PROGRAM	
RELIABILITY PROGRAM PLAN	
*PARTS, MATERIALS & PROCESSES PROGRAM PLAN (73-2C)	
PARTS SCREENING PLAN	
PMP QUALIFICATION PLAN	APPROVED PROCESSES
PARTS QUALIFICATION TEST RESULTS	
MATERIALS QUAL. DATA	
PROCESS QUAL. DATA	
DPA PROCEDURES AND RESULTS	
RECEIVING INSPECTION RESULTS & TREND ANALYSIS	
QUALITY ASSURANCE PLAN	
TEST PLANS AND PROCEDURES	QUALITY REQUIREMENTS
SUBCONTRACT MANAGEMENT	
PATENT RIGHTS	PATENT RIGHTS
COST ACCOUNTING STANDARDS	
RIGHTS IN DATA	RIGHTS IN DATA
AFFIRMATIVE ACTION FOR HANDICAPPED WORKERS	
AFFIRMATIVE ACTION FOR DISABLED VETERANS AND VETERANS OF THE VIETNAM ERA	
WORK MEASUREMENT	
EQUAL OPPORTUNITY	EQUAL OPPORTUNITY
FAIR LABOR STANDARDS ACT	
EXAMINATION OF RECORDS BY COMPTROLLER GENERAL	
TRUTH IN NEGOTIATIONS	
EXCESS PROFIT	
CONTRACT WORK HOURS AND SAFETY STANDARDS ACT	
UTILIZATION OF SMALL BUSINESS CONCERNS	
UTILIZATION OF LABOR SURPLUS AREA CONCERNS	
UTILIZATION OF MINORITY BUSINESS ENTERPRISES	
CLEAN AIR AND WATER	

MISSION ASSURANCE CONFERENCE
SUBCONTRACT MANAGEMENT

DETECTOR PROCUREMENT

PART SPEC REV	CONFIGURATION DESCRIPTION	SUPPLIER PRICE
B	WITH FIRST TECH CHANGES	\$84K FIXED PRICE
C	NOT SUBMITTED FOR QUOTE	
D	INCORPORATED LATER - COMMENTS - 1 FAILURE ALLOWED FOR SUBGROUPS 2-6 COMBINED	\$104K ROM
E	INCORPORATED CUSTOMER COMMENTS AT SUPPLIER MTG SEPT 20-21 . ADDED REWORK PROVISIONS . INCREASED LOT SAMPLE SIZE FOR QUAL TEST . DECREASED FAILURES ALLOWED FROM 1 TO 0 FOR SUBGROUPS 3&4 . DELETED THERMAL SHOCK . ADDED ACCELERATION TEST DURING QUAL . ADDED INSPECTION LOT DEFINITIONS	\$325K ESTIMATE CP CONTRACT 6 MOS SCHED SLIDE

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SUBCONTRACT MANAGEMENT

REQUIREMENTS FLOW DOWN

SUBCONTRACT:

- TERMS & CONDITIONS
- PROCUREMENT SPECIFICATION
- STATEMENT OF WORK

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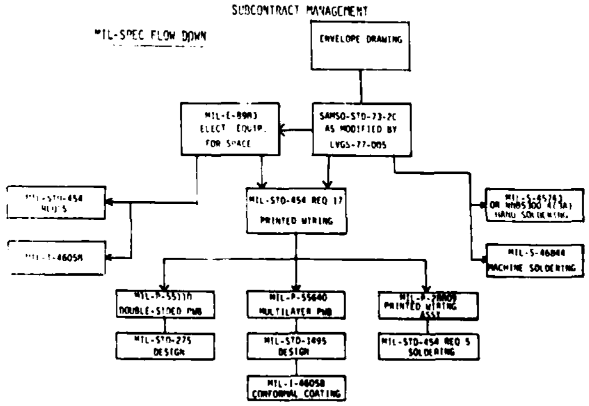
SUBCONTRACT MANAGEMENT

MIL-SPEC FLOW DOWN



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SUBCONTRACT MANAGEMENT

73-2C PERSPECTIVE

PROGRAM ELEMENT	STRAIGHT MIL SPEC PROGRAM	M^2 TYPE PROGRAM	IUS 73-2C PROGRAM
PARTS COST			
(OVERALL)	X	5X	8X
(IC'S)	X	6X	16X
PMP ENGINEERING	X	2.2X	4.4X
PMP PROCUREMENT SCHEDULING	X	2.5X	3X
MANUFACTURING EFFORT	X	1.05X	1.1X
Q. A. EFFORT	X	1.5X	3X

MISSION ASSURANCE CONFERENCE
SUBCONTRACT MANAGEMENT

SUGGESTIONS FOR IMPROVEMENT

- STANDARDIZE REQUIREMENTS, I.E. FIX MIL-SPECS DON'T INVENT REPLACEMENTS
- EARLY AND CLEAR IDENTIFICATION OF REQUIREMENTS
- CONDUCT BIDDERS BRIEFING TO IDENTIFY AND EXPLAIN NEW AND UNUSUAL REQUIREMENTS
- FOR REQUIREMENTS SUCH AS 73-2C PUT CUSTOMER REPRESENTATIVE ON SITE IN PRIME CONTRACTOR'S PLANT TO HANDLE PM&P PROBLEMS IN REAL TIME

SUBCONTRACTOR PROBLEMS WITH PRIMES
AND COMPONENT SUPPLIERS UNDER
SAMSO 73-2C

Sam Panella
Ed Thibodeau
Hamilton Standard

What Is Good About 73-2C

- ESTABLISHES THE MINIMUM REQUIREMENTS FOR A PMP CONTROL AND STANDARDIZATION PROGRAM FOR SPACEBORNE EQUIPMENT.
- RESTRICTS THE USE OF PMP WHICH HAVE BEEN DEFINED AS RELIABILITY RISKS
- ESTABLISHES UNIFORM SCREENING REQUIREMENTS
- ESTABLISHES A UNIFORM DERATING POLICY

Working With 73-2C

- DOCUMENT WAS NOT MATURE
- DOCUMENTATION REQUIRED TO GET PMP APPROVAL WAS EXCESSIVE
- APPROVAL CYCLE TIME FOR NSPAR'S AND SPECIFICATIONS WAS EXCESSIVE
- SUBCONTRACTORS WERE NOT ALLOWED TO USE MATERIALS AND PROCESSES WITH WHICH THEY ALREADY HAVE EXPERIENCE WITHOUT DETAILED JUSTIFICATION
- USE OF EXISTING DRAWINGS FOR STANDARD MATERIALS WAS NOT AUTHORIZED
- APPROVED VENDOR LISTS AND COORDINATED PROCUREMENT MAY BE A LEGAL (ANTI-TRUST) PROBLEM
- SOME REQUIREMENTS ARE FOUND IN FOURTH TIER DOCUMENTS

Evolution Of Screening Requirements

• SAMSO–STD 73–2C	2 SEPTEMBER 1975
• SAMSO–LVGS 77–005	1 JULY 1977
• CHANGES TO SAMSO–LVGS 77–005	28 FEBRUARY 1979
• PROPOSED CHANGES TO SAMSO–LVGS 77–005 FOR THE PRODUCTION PHASE OF THE PROGRAM	26 MARCH 1980
• OPTION TO USE ERMIL CAPACITORS AND RESISTOR, TCP–0121	9 APRIL 1980

Buying Parts To 73-2C

- SOME VENDORS REFUSE TO SUPPLY PARTS
- NO VENDOR WILL ACCEPT IT FOR SMALL ORDERS
- LOT REJECTION REQUIREMENTS INCREASE THE COST SIGNIFICANTLY
- THE NUMBER OF VENDORS FROM WHICH COMPONENTS CAN BE BOUGHT IS RESTRICTED

Lot Jeopardy Screens

- SCANNING ELECTRON MICROSCOPY (SEM)
- PARTICLE IMPACT NOISE DETECTION (PIND)
- PERCENT DEFECTIVE ALLOWABLE (PDA)
- DESTRUCTIVE PHYSICAL ANALYSIS (DPA)
- LOT QUALITY TESTS (QUALIFICATION OR QUALITY CONFORMANCE)

Interface With Prime Contractor

- SAMSO–STD 73–4 NOT INCORPORATED INTO THE PPSL
- USE OF THE SPECIFICATION APPROVAL CYCLE FOR OTHER THAN WHAT IT WAS INTENDED
- INFLEXIBILITY IN ADMINISTERING THE PROGRAM REQUIREMENTS
- ENFORCEMENT OF INEFFECTIVE PART SCREENS

Ineffective Part Screens

- X–RAY TANTALUM–TANTALUM WET SLUG CAPACITORS
- N–RAY TEMPERATURE COMPENSATED CERAMIC CAPACITORS
- PERFORM FIST ON TEMPERATURE COMPENSATED REFERENCE DIODES

Recommendations

- A SYSTEM FOR FASTER TURN AROUND ON NSPAR AND SPECIFICATIONS APPROVAL SHOULD BE IMPLEMENTED
- FLEXIBILITY IN ALLOWING SUBCONTRACTORS TO USE MATERIALS AND PROCESSES WITH WHICH THEY ALREADY HAVE EXPERIENCE
- USE OF EXISTING DRAWINGS FOR STANDARD MATERIALS SHOULD BE AUTHORIZED
- ALL IMPOSED SPECIFICATIONS SHOULD BE DEFINED IN 73–2C
- SUBCONTRACTORS SHOULD BE FREE TO USE MORE OF THE PARTS FROM THE P–95 MONITORED LINE
- SUBCONTRACTORS SHOULD BE REQUIRED TO BUY EACH PART TYPE FROM TWO SOURCES
- SEM SHOULD BE DONE BY THE CUSTOMER, NOT BY THE VENDOR
- DPA SHOULD BE PERFORMED AS EARLY IN THE PROGRAM AS POSSIBLE

Major Material Problems

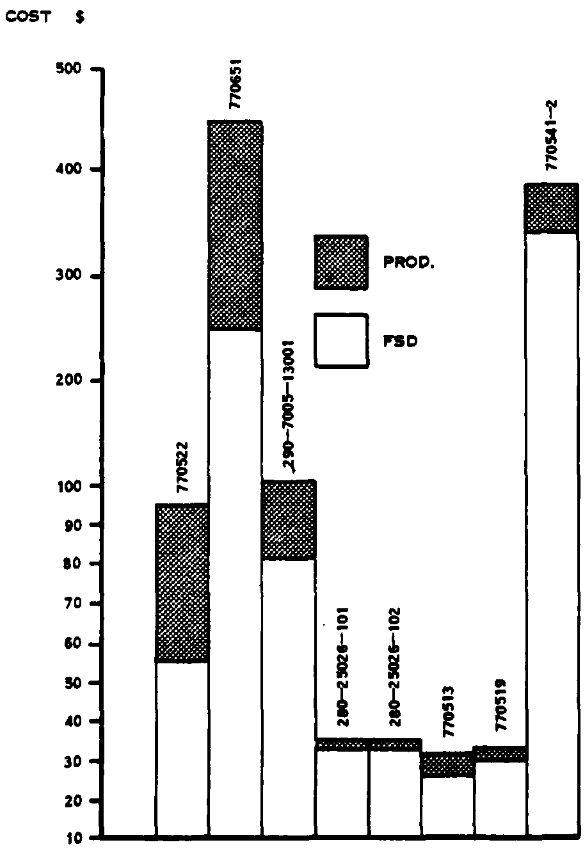
I. COST

- RISING COST DUE TO 73–2C SCREENS
- SMALL PRODUCTION QUANTITY

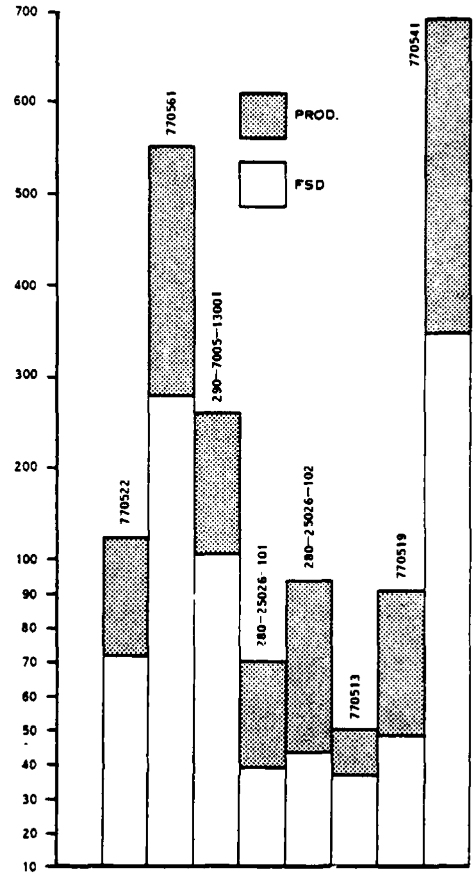
II. AVAILABILITY

- VENDOR LEAD TIME
- SUCCESS IN MEETING SPEC REQUIREMENTS

Material Cost FSD versus Production (Excluding Lot Charges)



Material Cost FSD versus Production (Including Lot Charges)



Purchase Larger Buy

ADVANTAGES

A. UNIT COST REDUCED

B. PARTS AVAILABILITY

C. SUPPORT COST REDUCED

D. NEGOTIATION POSITION

DISADVANTAGES

A. LARGER CAPITAL TIED UP

B. INVENTORY VERSUS INVESTMENT

73-2C Availability

HISTORY

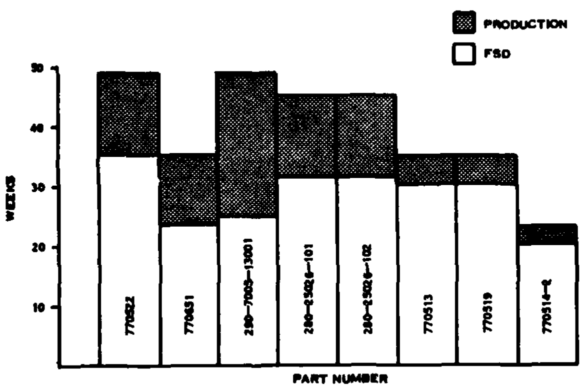
VENDOR PROMISES ON ACTIVE DEVICES PRIOR TO GROUP B AVERAGED 30 WEEKS

- ONLY 15% OF THE PARTS CAME IN ON TIME
- AVERAGE WAS 50 WEEKS
- SOME PARTS ALMOST TWO YEARS LATER HAVE NOT RECEIVED COMPLETE ORDER

PRODUCTION

- VENDOR QUOTING LONGER LEAD TIMES INITIALLY

Del. FSD versus Production



Alternatives

- BUY PARTS LARGER QUANTITIES
- DUAL SOURCING ORDERS
- START MULTIPLE LOTS (DIFFERENT METALIZATION)
- USE OF HI REL SCREENING COMPANIES
- INDUSTRY TRENDS WILL CHANGE DELIVERY
  - (1) NSC QUITS HI REL NEGOTIATION
  - (2) SIGNETICS WILL NO LONGER AGREE TO SEM REQUESTS ON PROMS
  - (3) AMD SIMILAR TO NSC AND SIGNETIC

Suggestions

- OFFER VENDORS INCENTIVES
- OFFER VENDORS PREMIUM
- PROVIDE EDUCATIONAL AWARENESS PROGRAM
- NEGOTIATE DX PRIORITY RATING

SUMMARY OF ISSUES AND RECOMMENDATIONS

SUBCONTRACT MANAGEMENT

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Subcontract Management Communications

<u>Issue</u>

Improve communication between the customer and subcontractor.

<u>Recommendations</u>

- o Pre and post award seminars (customer, contractor, geographical) awareness of program objectives. Awareness of contract content and meaning. Subs attend with prime.
- o Prime contractural direction that these meetings be held.
- o Sub contractors attend specialized meetings and review, (i.e., PMPCB) both at the contractor and at rotated locations.
- o Clear contractual definition of customer entry to subs. SPO must notify prime of visits to subs.
- o Continue/expand mission assurance conferences to encourage subcontractor participation.
- o Invite all the subs to visit the prime to check commonality, coordinated purchases, a <u>team effort</u> for the entire procurement process, getting the subs talking to each other, to understand lessons learned, to explain flowdowns.

2. Subcontract Requirements

<u>Issue</u>

Customer requirements are proliferating while industry is striving to be more autonomous and less controlled (monitored). Need understanding and generally same approach to implementing same requirements.

<u>Recommendations</u>

- o Conduct post award reviews with subs for in depth review of application of requirement to subs.
- o Highlight reason for origination of requirement in pre-award conferences.
- o Conduct periodic review of specifications to modify/cancel to reflect current needs and specifically review against original reason for specification.
- o Provide appendix to spec's that allows for specific paragraph by paragraph applicability that ties to program phasing.
- o Include customer, contractor, sub-contractor, AFPRO, DCAS in a post award understanding of of requirements and document results as memorandum of agreement as a part of contract.
- o Re-examine need for requirements in specs. Requirements are usually input to solve a problem, but the problem may be non-existent now or greatly modified by current technology.

3. Subcontract Program Management

<u>Issue</u>

Program Management (both industry and customer) not involved early in specifications. Is the boilerplate is what they want without seeing future costs ?

<u>Recommendations</u>

- o Allow more time for draft RFP's to understand "ility" requirements, especially those large potential impacts on cost or schedule.

- Contractors must identify (without government penalty) those long lead items which preclude contractors from meeting (planned or present) long lead schedules - identify schedule constraints.

- Industry should consider competition secondary in the single area of consolidating buys from small buys of long-lead items. Use AIA or NSIA. Or use JAMAL (Joint Aeronautical Material).

10. Surveys and Audits

Issue

SPO's do not realize that many Contract Administration Services (especially AFPRO's) already have answers to surveys such as the Manufacturing Management Production Capability Reviews. But this is not mentioned in AFSCR 84-2.

Recommendations

- AFSCRs be revised to include statements in each reg that AFPROs are involved/not involved in certain areas. SPOs do not normally understand AFPRO functions and capabilities this causes duplicate effort and wasted time and money.

- Accept the centralized data bank of surveys (CASE), and establish Quarterly report on each subcontractor.

- SPOs should be made aware of how many audits were done in a particular plant over a period of time. Put this info into GIDEP.

- Contractor self-audit function should be the only contractor group SPOs audit. Then, if the contractor audit group is rated excellent, the government team won't have the need to come in. Incentivize the contractor to do this.

- When SPOs go in for an audit, they should spend minimum time (depend on the cognizant CAS organization) emphasizing only their program-unique aspects.

- Get the cognizant CAS to certify that areas of the SPO audit check list are OK - thereby allowing the SPO to maximize his time in plant.

- SPOs should get one person per program to go in-plant - or a multi-agency review (like once per year).

11. Subcontract Flowdown

Issue

Industry and government are both providing too much boilerplate to subs to be read and understood.

Recommendations

- Prime scrub boilerplate before flowdown to subs.

- Industry (AIA, NSIA) with SBA conduct study on most meaningful flow down requirements. Study for all subcontract tiers.

- Industry (AIA & NSIA) should suggest increasing flexibility to DAR requirements to the DAR council.

12. Subcontract Management - Public Law 95-507

Issues

How can government tailor the application of public law 95-507 to the requirements of the individual contracts and still meet the statutory objectives ?

Recommendations

- After point by point review for areas requiring modifications have primes/subs and customer discussions result in a letter of understanding on specification implementation.

- PMP boards capability to interpret (authority) specs - publish output to program office for approval - shorten the cycle for approval. Distribut e agreement to affected parties, including AFPRO/DCAS.

Subcontract Management - Tailoring

Issue

Tailoring fear - lose to competitor or offend the "author" of the requirement.

Recommendations

- Provide positive motivation to tailoring in RFP, i.e., proposal will get additional points for each tailored approach.

- Tailoring needs to reflect cost savings and the assurance of no/little loss of performance - must sell approach.

- Continue tailoring throughout draft and just prior to best and final - provide as alternate approaches.

- Customer "ilities" need to expect and treat suggested changes as good to both customer and contractor.

- Make tailoring a positive factor during RFP phase - dollars, source selection criteria, creativity, tailoring (you must sell your tailoring - why it impacts cost and not reliability).

8. Subcontract Management - Raw Materials

Issues

Inferior raw materials being received having poor traceability (COC's), raw material specifications need to be updated to today's needs.

Recommendations

- Raw material industry must accept responsibility for providing products that meet requirements and its associated certifications.

- Sample and destructive test incoming raw materials.

- Verify adequacy of Certificates of Conformance (COC) especially on flight critical components. COC must specify precisely what requirements were met.

- Industry associations establish review of material specifications to determine adequacy for space.

- Industry associations initiate communications with raw material industries.

9. Subcontract Schedules

Issues

Unrealistic schedules for parts (customer level vs component industry).

Recommendations

- Become more knowledgeable of lead time changes based on needs and experience.

- Pool industry and government lead time charts.

- Put inducements into RFP to encourage contractor highlighting key cost/schedule impact with no compromise to performance.

- Look hard at standard "ility" boilerplate being imposed as related to hardware application.

- Program managers should be in detail loop review of requirements being imposed - especially being aware of contractor position.

- Need to get to the project officers to listen to prime on cost impacts - not just have "filtered" thru their people.

4. Subcontract Management Risk

<u>Issue</u>

Subtier suppliers do not want to meet Aerospace requirements and do not accept contracts.

<u>Recommendations</u>

- Ease the suppliers' lack of resources by primes taking responsibility for some of tasks, i. e., part procurement, qual testing, etc.

- Dispel fears of awesome specification requirements by awareness meetings that address specification applicability.

- Provide incentive compensation to encourage suppliers to accept high risk projects.

- Provide front end money to encourage specific industry as a high risk technology or cover long lead items/materials.

- Cost consideration may not be the best criteria for proposal judgement. Make this the last element after technical input.

5. Subcontract Specifications

<u>Issues</u>

New specs (73-2C, MIL-S-1546/7) have tremendous cost impact that generally are unknown at time of RFP.

<u>Recommendations</u>

- Seminar to explain just what the new specs want, the costs entailed, the knowledge of program managers enhanced from the user point of view.

- Mutual interpretation between customer and industry to understand the new specs and the impact thereof to eliminate fears.

- Define the title and the scope of each spec up front so that people can understand its application better.

- Develop a new spec with a matrix to highlight changes in the spec on what applies to each contract.

- Requirement to collect costs for parts requirements. Requirement for primes and subs to estimate the cost of the parts over a period of time per number needed. Advise program managers of cost impact.

- Have conferences on education exercises for government and industry appropriate for new special requirements.

6. Subcontract Specification Interpretation

<u>Issue</u>

Specs such as (73-2C) have well meaning birthrites, but have become inflexible to allow for modified implementation.

Recommendations

- o Conduct a tutorial program for government and industry to explore requirements of 95-507 and what the contractor is obligated to do and exactly when.

- o Seek a contract from the government to contact and educate on many of the small businesses or possible in a specified time and make them aware of aerospace requirements.

- o Could contractors be judged on a yearly basis instead of a contract by contract basis ? Industry association inputs to SBA to promote change in statute 95-507.

WORKSHOP D

TEST EFFECTIVENESS

Chairmen

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B. Keegan
Staff Engineer
Assurance Management & Test Policy Office
Goddard Space Flight Center, NASA

Coordinators

L.L. Jepsen, AF Space Division

Status of MIL-STD-1540	L.L. Jepsen, SD
Thermal Cycling System Test	R.B. Laube, Aerospace
Current Boeing Experience with MIL-STD-1540A on Component Tests	H. McDaniel, Boeing
Role of Automated Testing as Regards Mission Assurance	G.T. Yamada, LMSC
Test Accommodation in Design	J.A. Durshinger, TRW
Evaluation of Test Effectiveness Results	A. Krausz, TRW
Test Software	E.W. Dusio, RCA Astro Electronics

STATUS OF MIL-STD-1540 (SYNOPSIS)

L.L. Jepsen
Staff Test and Evaluation Engineer
Space Division (USAF)

MIL-STD-1540A, Test requirements for space vehicles, in use since 1974 is in the process of being updated and revised. A draft revisions has been circulated on a somewhat limited basis for comment. A lot of comments and suggested changes have been received from industry and Air Force offices. Areas and specific topics that will most likely be changed are presented. Additional review and comment opportunities will occur before publication, now forecast for early 1981.

MIL-STD-1540 CHANGES
OVERALL

- o SHUTTLE ERA TEST CONSIDERATIONS
- o SEPARATE MANAGEMENT SYSTEMS/CONTROLS FROM TECHNICAL REQUIREMENTS
- o SOFTWARE AS PART OF THE SYSTEM
- o DEFINITIONS - CLARIFY AND CLEAN UP
- o GET RID OF SUBTIER DOCUMENTS - GOAL

MIL-STD-1540 CHANGES
TECHNICAL AREAS

- o THERMAL VACUUM - THERMAL CYCLING - THERMAL BALANCE TESTING
- o RETEST REQUIREMENTS/GUIDELINES
- o PROTOFLIGHT/BUY-ONE-FLY-ONE TEST PROGRAMS
- o SEQUENCE OF ENVIRONMENTS
- o REDUNDANCY TESTING/BURN-IN
- o BURN-IN DURATIONS
- o ACCEPTANCE TEST OF QUAL ARTICLES
- o PRELAUNCH VALIDATION - MAJOR REWRITE

MIL-STD-1540 CHANGES
TECHNICAL AREAS

- o DEVELOPMENT TESTS - BUT NOT DETAILED
- o SUBASSEMBLY (CARD/BOARD) - GET IN OR OUT
- o 6 B VS 3 B (SOME MORE)
- o REQUIRED VS OPTIONAL DESIGNATIONS
- o TEST CONDITION TOLERANCES
- o PARTICLE SCREENING TESTS (BOX LEVEL)
- o THERMAL DWELL VS STABILIZATION
- o THERMAL CYCLE - RATE OF TEMPERATURE CHANGE
- o RADIATION/HARDENING TESTS - MAYBE

THERMAL CYCLING SYSTEM TEST (SYNOPSIS)

R.B. Laube
Ground Systems and Test Department
The Aerospace Corporation

This briefing focuses on the question "Can system level test effectiveness be inproved by adding a system thermal cycling test ?" Existing data is somewhat limited but indicates that system level thermal cycling is an effective test. Additional data and analysis is needed to assess tradeoffs, if any, with thermal vacuum tests and examine duration, rate of temperature change, dwell times (soak), and other parameters for the "best" test approach. Results of this analysis should be reflected in changes to MIL-STD-1540.

MISSION ASSURANCE CONFERENCE
TEST EFFECTIVENESS WORKSHOP
THERMAL CYCLING SYSTEM TEST

R.B. LAUBE

APRIL 1980

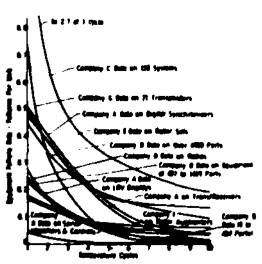
OBJECTIVE

- o STIMULATE PANEL DISCUSSION
  - THERMAL CYCLING SYSTEM TEST PARAMETERS
  - ROLE OF THERMAL CYCLING SYSTEM TEST

THERMAL CYCLING TEST RATIONALE

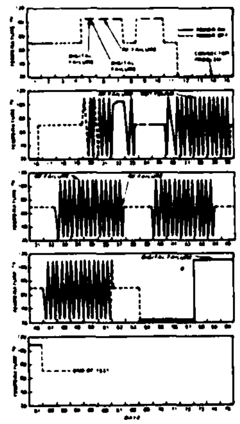
- o SIGNIFICANT NUMBER OF FAILURES ATTRIBUTED TO TEMPERATURE STRESSES DURING COMPONENT AND SYSTEM TEST
- o SYSTEM THERMAL CYCLING TEST CAN APPLY TEMPERATURE STRESSES FASTER, MORE UNIFORMLY, AND MORE ECONOMICALLY AT AMBIENT PRESSURE

SUMMARY OF INDUSTRY SURVEY DATA

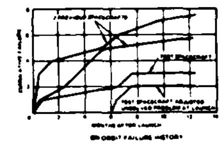


COMPANY	TYPE AND SIZE OF DATA SAMPLE	TEMP RANGE °F
A	80 RADAR SYS.	196
B	80 C&C SYS.	160
C	150 ELEC. SYS.	196
D	360 RADIOS	196
E	10 RADAR SYS.	126
F	270 RADAR AUG.	225
G	21 TRANSPOND	UNK.

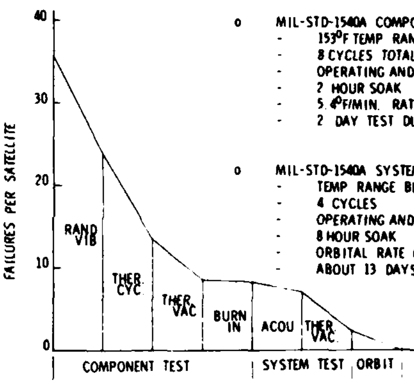
SYSTEM LEVEL THERMAL CYCLING TEST



- o TEST PARAMETERS
  - 85°F TEMP RANGE
  - 66 CYCLES TOTAL
  - OPERATING AND MONITORED
  - 2 SOAK CYCLES
  - 0.4°F/MIN RATE OF CHANGE
  - 42 DAY TEST DURATION



ENVIRONMENTAL TEST PROGRAM HISTORY
(5 SPACECRAFT)



- o MIL-STD-1540A COMPONENT THERMAL CYCLING
  - 153°F TEMP RANGE
  - 8 CYCLES TOTAL
  - OPERATING AND MONITORED
  - 2 HOUR SOAK
  - 5.4°F/MIN. RATE OF CHANGE
  - 2 DAY TEST DURATION
- o MIL-STD-1540A SYSTEM THERMAL VACUUM
  - TEMP RANGE BETWEEN ORBITAL EXTREMES
  - 4 CYCLES
  - OPERATING AND MONITORED
  - 8 HOUR SOAK
  - ORBITAL RATE OF CHANGE
  - ABOUT 13 DAYS MINIMUM

SYSTEM THERMAL CYCLING ISSUES

- o TEMPERATURE RANGE
  - ALL COMPONENTS REACH ACCEPTANCE TEMPERATURE EXTREMES
- o HOW MANY CYCLES IS ENOUGH
  - FAILURE FREE CYCLES
- o SOAK CYCLES
  - ARE THERE FAILURES MANIFEST ONLY AT TEMPERATURE EXTREMES
- o TEMPERATURE RATE OF CHANGE
  - IS A RAPID CHANGE RATE MORE EFFECTIVE
  - IS A RAPID CHANGE RATE FEASIBLE -- WORTH THE COST
- o MOISTURE PROBLEMS
- o HOW SHOULD SYSTEM THERMAL CYCLING TEST BE SPECIFIED IN MIL-STD-1540B

ROLE OF THERMAL CYCLING SYSTEM TEST

- REPLACEMENT OF THERMAL VACUUM TEST NOT FEASIBLE
  - VERIFICATION OF THERMAL CONTROL SYSTEMS, CORONA, MULTIPACTION, DIELECTRIC CHARACTERISTICS AND OUTGASSING

- CAN MIL-STD-1540 THERMAL VACUUM TEST BE TRUNCATED WITH A THERMAL CYCLING TEST
  - RUN ALL THERMAL VACUUM TESTS WITHIN THE TIME FOR TWO THERMAL BALANCE TESTS

- COSTS OF THERMAL VACUUM VS THERMAL CYCLING

CURRENT BOEING EXPERIENCE WITH MIL-STD-1540A ON COMPONENT TESTS (SYNOPSIS)

Mr. Herbert McDaniel
Boeing Aerospace Co.
Payload System Assurance Manager - RSLP

Boeing is in the process of developing and testing an upper stage space vehicle. Over 250 component level tests have been accomplished in accordance with MIL-STD-1540A. This represents about 30 percent of the planned component qualification program. Only 25 failures have occurred to date with 4 of these attributed to test procedural errors. The findings based on this testing bring up the following issues

1) Sequence Changes

   Thermal cycling tests were very effective in finding failures on one type of component. Should thermal cycling run before the other test environments?

2) Burn-in Time

   All failures found occurred during the first few thermal cycles. Should the 300 hours of burn-in time be reduced?

3) Thermal Vacuum Acceptance

   No failures occurred in thermal vacuum when thermal cycling was performed first. Should thermal vacuum acceptance testing be made optional on low voltage components?

4) Tolerances

   Waivers were approved because the ± 3 db tolerance on pyroshock could not be held. Should MIL-STD-1540 be revised to widen the tolerance to one the test community can make?

5) Pyro Screening

   Pyrotechnic shock followed by low level vibration bursts was not effective in finding failures. Should this test be added to MIL-STD-1540 as proposed?

TEST EFFECTIVENESS SESSION: ROLE OF AUTOMATED TESTING AS REGARDS MISSION ASSURANCE

G.T. Yamada
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Space Systems Division

Abstract

Current Automated Test Systems (ATS) have provided effective testing under cost and schedule restrictions. It has effectively provided expanded test capabilities in response to three primary requirements: (1) increased Unit Under Test (UUT) complexity; (2) increased safety requirements for UUT, test system, and personnel; and (3) kept pace with technological advances. It is also known that ATS have suffered many developmental problems (cost and schedule impacts) and operational problems (performance and reliability).

Most general scenarios of the future indicate quantum jumps in space mission requirements, use of advanced microtechnology and material technology products (VLSI, VHSIC, composites), and safety requirements. The resultant increased need for higher performance in ATS magnifies increasing ATS problems in development cost and schedule and the availability of qualified ATS personnel. Productivity problems in test operations will be increased if these improved ATS are not available.

A multifaceted "program" must be initiated in order to effectively solve the ATS situation without having to restrict customer requirements. Standardization of common spacecraft components and subsystems, improvements in ATS project management techniques, emphasis on an effective education and training program for ATS professionals, and improvements in ATS design and performance are but a small part of a larger effort. A more definitive "program" must be defined in a customer/ATS industry/contractor study that speci-specifically addresses ATS in the space business.

WHAT IS ATS?

- MIL-STD-1309: AUTOMATIC TEST EQUIPMENT (ATE)
- MIL-STD-415D: AUTOMATIC TEST EQUIPMENT (ATE)
  - AUTOMATIC MONITORING EQUIPMENT (AME)
  - AUTOMATIC CHECKOUT EQUIPMENT (ACE)
- AUTOMATIC TEST SYSTEMS (ATS): A FULLY INTEGRATED AUTOMATED TEST SYSTEM THAT........

BACKGROUND

- PRIMARY PROBLEMS
  - COMPLEXITY: INTEGRATION LEVEL
  - SAFETY: SYSTEM, UUT, AND PERSONNEL
  - TECHNOLOGY: DIGITAL APPLICATIONS

COMPLEXITY

- o CURRENT ATS HAS:
  - INCREASED TESTING THROUGHPUT BY USING ITS SPEED, DATA MANAGEMENT, SELF-TEST, AND STANDALONE OPERATION CAPABILITIES.
  - INCREASED TEST FLEXIBILITY BY PROGRAMMABILITY, INTERFACING FLEXIBILITY, FLEXIBLE DISPLAY AND CONTROL CAPABILITIES.
- o IMPACT ON TEST EFFECTIVENESS:
  - ALLOWS FOR FLEXIBLE AND INCREASED VARIETY OF TESTS TO BE PERFORMED WITH MORE VARIETIES OF STIMULI AND BETTER DATA PROCESSING.
  - AVOIDS MISSING ERROR CONDITIONS.
- o CURRENT ATS HAS SUFFERED PROBLEMS IN:
  - LONG TEST DEVELOPMENT TIME (DUE TO UNFAMILIARITY WITH USE OF ATS, MISUNDERSTANDING OF ATS PERFORMANCE CAPABILITIES, AND NEED TO UNDERSTAND/USE SIGNAL PROCESSING TECHNIQUES) LEADS TO LEAVING OUT MANY CAPABILITIES IN ORDER TO MEET SCHEDULE AND COST GOALS.
  - ATS CAPABILITIES ARE NOT SUFFICIENT FOR MULTI-PROGRAM USE (DESIGNED FOR "TARGET" PROGRAM ONLY).
  - INTERFACE BETWEEN UUT AND ATS ARE TOO COMPLEX; THUS DEGRADING PERFORMANCE AND INCREASING COSTS.
  - INADEQUATE SYSTEM RESPONSE.

SAFETY

- o CURRENT ATS HAS:
  - PROVIDED TEST REPEATABILITY AND ACCURACY.
  - PROVIDED FOR SELF-TESTING.
  - PROVIDED FOR UP-TO-DATE TEST STATUS OF ATS, UUT, AND OPERATOR ACTIONS.
  - PROVIDED HANDS-OFF TESTING OF UUT UNDER NORMAL TEST OPERATIONS.
- o IMPACT ON TEST EFFECTIVENESS
  - IMPROVED TEST CONTROL
  - IMPROVED DIAGNOSTIC CAPABILITIES
  - IMPROVED ASSURANCE OF TEST EQUIPMENT PERFORMANCE.
- o CURRENT ATS HAS SUFFERED PROBLEMS IN:
  - INADEQUATE MAN-MACHINE INTERFACE ("NEED THE PROGRAMMER TO OPERATE IT")
  - INADEQUATE UNDERSTANDING BY TEST OPERATIONS ON WHAT ACTIONS THE ATS HAS TAKEN TO CONDUCT A TEST.
  - ELECTROMAGNETIC RADIATION THAT AFFECTS OTHER TEST EQUIPMENT AND SECURITY REQUIREMENTS.
  - SYSTEM RELIABILITY.

TECHNOLOGY

o CURRENT ATS HAS:

- PROVIDED COMPATIBILITY WITH GENERAL TREND TOWARD MORE USE OF DIGITAL COMPONENTS.
- PROVIDED ANALOG AND DIGITAL PROCESSING IN THE SAME SYSTEM.
- ALLOWED FOR EASIER ATS UPGRADING.
- PROVIDED FOR INTEGRATION OF CONTROL, COMMANDING, AND DATA ACQUISITION.

o IMPACT ON TEST EFFECTIVENESS:

- PROVIDES DATA COMPATIBILITY BETWEEN UUT AND ATS.
- EASIER TEST INSTRUMENT UPGRADING

o CURRENT ATS HAS SUFFERED PROBLEMS IN:

- KEEPING UP WITH CURRENT ELECTRONIC CIRCUIT DENSITIES. STATISTICAL TESTING MAY BECOME PREVALENT IN ORDER TO REDUCE TESTING COSTS AND TIME.

STANDARDIZATION

- PROBLEM AREAS
  - COMMERCIAL, INDUSTRIAL, GOVERNMENT (INCL MILITARY) RELATIONSHIP: MUST/WILL HAVE TO IMPROVE DUE TO NECESSITY (COST AND AVAILABILITY) AND PERFORMANCE REQUIREMENTS
  - GOVERNMENT (INCL MILITARY) MUST IMPROVE ON SHARING ATS AS MUCH AS POSSIBLE
- POSSIBLE ALTERNATIVES
  - A SIMILAR STUDY TO THE INDUSTRY/JOINT SERVICES AUTOMATIC TEST STUDY RECENTLY PRESENTED TO THE JOINT LOGISTICS COMMANDERS MUST BE CONDUCTED FOR SPACE APPLICATIONS
- GUIDELINES

PROJECT/SYSTEMS MANAGEMENT APPROACH

- RELATIONSHIP TO PROJECT MANAGEMENT ORGANIZATION: TEAM CONCEPT

- METHODOLOGY

  - SYSTEMS APPROACH:

    TECHNICAL - REQUIREMENTS ANALYSIS; SYSTEMS DEFINITION; SYSTEMS AND SUBSYSTEMS DESIGN; DEVELOPMENT; TEST, VERIFICATION, AND VALIDATION; OPERATIONS AND MAINTENANCE; END-OF-USE.

    NONTECHNICAL - PROJECT CONTROL, MATRIX ORGANIZATION.

- GUIDE LINES

  - PARTITIONED RESOURCES APPROACH

  - PIECE-MEAL APPROACH

  - TRIAL-AND-ERROR APPROACH

MAJOR ATS PROJECT IMPACTS

- CUSTOMER
  - DEVELOPMENT AND USE OF ATS MUST INCREASE SIGNIFICANTLY
  - ATS DEVELOPMENT AND USE WILL APPROACH PROJECT SIGNIFICANCE. IT WILL NOT REMAIN SIMPLY AS AN ADJUNCT TO A PROGRAM.
  - MUST/NEED TO INITIATE AN OVERALL "INDUSTRY" STUDY ON ATS.

- MANAGEMENT
  - PROJECT-ORIENTED: QUALIFIED ATS-ORIENTED DEVELOPMENT AND OPERATIONS TEAM
  - USE OF SYSTEMS APPROACH
  - NEED TO GET ACTIVELY INVOLVED IN MAKING SURE THAT THERE IS AN ADEQUATE SUPPLY OF QUALIFIED ATS PERSONNEL;

- ATS DEFINITION
  - MODULAR HARDWARE AND SOFTWARE THAT PERFORMS AS A HIGHLY INTEGRATED SYSTEM.
  - STANDARDIZED INTERFACES
  - HUMAN ENGINEERED FOR OPERATIONS AND MAINTENANCE
  - REALTIME, CLOSED LOOP OPERATION
  - DISTRIBUTED PROCESSING WITH CENTRAL CONTROL
  - PORTABLE
  - USE OF HIGH LEVEL TEST LANGUAGE
  - AUTOMATED TEST PROCEDURE GENERATION
  - EXTENSIVE USE OF SYSTEM ARCHITECTURE ANALYSIS
  - DOCUMENTATION.

TEST ACCOMODATION IN DESIGN (SYNOPSIS)

J.A. Durschinger
TRW/DSSG

Satellite design features to facilitate system testing needs to be an integral part of the design process. Hardware and design realities must be recognized - there are limitations, opportunities, and "that is how it is" situations. Many tradeoffs and associated "payoffs" must be considered. Some specific recommendations are offered for both test and design engineering people.

WHAT IS TEST ACCOMMODATIONS?

- IT IS SATELLITE DESIGN TO FACILITATE SYSTEM TEST.
- IT IS A FACTOR IN THE SATELLITE DESIGN PROCESS WHICH INTEGRATES TEST REQUIREMENTS INTO THE SYSTEM DESIGN.

INCORPORATING TEST ACCOMMODATIONS INTO SATELLITE DESIGN RECOGNIZES HARDWARE AND DESIGN REALITIES

- UNITS DO FAIL
- DESIGN MISTAKES DO OCCUR
- DESIGN CHANGES DO OCCUR
- GENERIC DEFECTS ARE DISCOVERED
- SOME TYPES OF EQUIPMENT REQUIRE SPECIAL STORAGE
- SOME TYPES OF EQUIPMENT MUST BE INSTALLED LATE DURING PRE-LAUNCH OPERATIONS
- TOTAL SYSTEM HARDWARE MUST BE TESTED, NOT JUST SYSTEM FUNCTIONS
- PERFORMANCE BUDGETS DO NOT ALLOW FLYING ALL TEST INSTRUMENTATION

TRADE OFFS ARE REQUIRED TO DEFINE TEST ACCOMMODATION REQUIREMENTS

- HARDLINE CONNECTIONS VS TELEMETRY MEASUREMENTS
- DATA BUS INTERFACES VS COMMAND/TELEMETRY INTERFACES
- ONE TIME INSTALLATION VS REMOVAL/REPLACEMENT/REUSE
- TEST TIME COSTS VS EGSE COST
- TEST INSTRUMENTATION VS TELEMETRY MEASUREMENTS
- STIMULATION VS SIMULATION
- MISSION PROFILE TESTING VS FUNCTION TESTING
- LAUNCH SITE TESTING VS SHIP AND SHOOT CONCEPT

WHAT IS THE PAYOFF FOR TEST ACCOMMODATION CONSIDERATIONS

- INCREASED ASSEMBLY AND TEST EFFICIENCY.
- ENHANCED HARDWARE AND PERSONNEL SAFETY.
- INCREASED THROUGHTNESS AND COMPLETENESS OF SYSTEM TESTING.
- FACILITATED DISCOVERY OF SUBTLE SYSTEM PROBLEMS.

SOME SPECIFIC TEST ACCOMMODATION RECOMMENDATIONS TO OUR ENGINEERING PEOPLE

- ESTABLISHING A DEDICATED COMMUNICATION FORUM TO WORK TEST ACCOMMODATION ISSUES BETWEEN TEST AND ENGINEERING.
- DEFINING QUANTITATIVE CLEARANCE REQUIREMENTS FOR SATELLITE HARNESS CONNECTORS.
- MOUNTING UNITS REQUIRING ALIGNMENTS ON THREE POINTS AND USING ADJUSTMENT SCREWS FOR ALIGNMENT.
- REQUIRING ALL ELECTRONIC UNITS CONNECTED TO THE SATELLITE MAIN POWER BUS TO BE CAPABLE OF RAMP POWER TURN-ON.
- TO THE MAXIMUM EXTENT POSSIBLE ATTACH ALL THERMAL BLANKETS WITH MECHANICAL FASTENERS, NOT TAPE.
- DEFINING STANDARDIZED TEST POINTS AND IN FLIGHT JUMPER CONFIGURATIONS FOR BATTERIES, SOLAR ARRAYS, AND POWER DISTRIBUTION SYSTEMS.

EVALUATION OF TEST EFFECTIVENESS RESULTS

Dr. A. Krausz
Chief Test Engineer
Assembly and Test Operations
Space Systems Division, TRW DSSG

This presentation will address three basic questions: What is test effectiveness? How can test effectiveness be measured? What is the test effectiveness of recent. spacecraft projects? These questions can be answered by focusing on the design and workmanship defects which must be found by testing and by considering the monetary and schedule cost of the test program. Data obtained from quality assurance records for several recent spacecraft projects will be presented which show the number of defects found during various phases of the testing program and during orbital operation. The data indicate that rough correlation exists between the number of orbital anomalies and the normalized number of factory test discrepancies. Although on-orbit operation of satellites has been excellent, some suggestions for improving the test programs are made.

QUESTIONS

- WHAT IS MEANT BY TEST EFFECTIVENESS?
- HOW CAN TEST EFFECTIVENESS BE MEASURED?
- WHAT IS THE TEST EFFECTIVENESS OF CURRENT SPACECRAFT PROJECTS?

MEASUREMENT OF TEST EFFECTIVENESS

- BASED ON TEST DISCREPANCIES (DEFECTS)
- DEFINITIONS
  - TEST EFFECTIVENESS = $\frac{\text{NUMBER OF DEFECTS FOUND BY TEST}}{\text{TOTAL NUMBER OF DEFECTS PRESENT}}$
  - ESCAPE RATIO = $\frac{\text{NUMBER OF DEFECTS NOT FOUND}}{\text{TOTAL NUMBER OF DEFECTS PRESENT}}$
- ASSUMPTIONS
  - DEFECTS EXIST PRIOR TO TEST
  - TESTS CAN LOCATE DEFECTS

WHAT IS TEST EFFECTIVENESS?

- SATISFACTION OF TEST OBJECTIVES
  - ALL OBJECTIVES
  - LOW COST
  - MINIMUM TEST TIME
- TEST OBJECTIVES
  - LOCATE AND ELIMINATE DEFECTS
  - DEMONSTRATE CONFORMANCE TO REQUIREMENTS

PROJECT A - CAUSE OF TEST DISCREPANCIES

DEFECT/CAUSE OF DISCREPANCY	TEST LEVEL				ESCAPE RATIO	
	COMPONENT	SPACECRAFT	LAUNCH BASE	ON ORBIT	E_c	E_o
PRODUCT DEFECTS						
PART FAILURE	68	10	1		13.9	
COMPONENT MANUFACTURING	112	19		1	14.5	0.7
COMPONENT DESIGN	174	20			13.8	
SPACECRAFT ASSEMBLY		14				
SPACECRAFT DESIGN		16	1	3		15
TEST INDUCED	13	5				
UNDETERMINED		11				
TOTAL	367	103	2	4	14.3	0.04
PROCEDURE DEFECTS						
DOCUMENTATION	110	34				
TEST EQUIPMENT	41	23	1			
OPERATOR ERROR	35	16	1			
TEST SETUP	18	3	1			
TOTAL	204	76	3			
NON-DEFECTS						
WITHIN TOLERANCE/WAIVER	78	21	2	4		
UNABLE TO REPEAT PROBLEM	29	13		1		
TOTAL	107	34	2	6		

NOTES: 4 spacecraft, 3 in orbit, 3 years of orbital performance

PROJECT B - CAUSE OF TEST DISCREPANCIES

DEFECT/CAUSE OF DISCREPANCY	TEST LEVEL				ESCAPE RATIO	
	COMPONENT	SPACECRAFT	LAUNCH BASE	ON ORBIT	E_c	E_o
PRODUCT DEFECTS						
PART FAILURE	38	4		1	13.6	2.3
COMPONENT MANUFACTURING	79	5	1	-	17.0	-
COMPONENT DESIGN	45	19	4	5	33.3	6.9
SPACECRAFT ASSEMBLY	-	18	-	-		
SPACECRAFT DESIGN		11	2	1		
TEST INDUCED	6	-	2			
UNDETERMINED	6	4	1			
TOTAL	174	61	11	7	19.9	2.9
PROCEDURE DEFECTS						
DOCUMENTATION	55	23	1			
TEST EQUIPMENT	62	4	1			
OPERATOR ERROR	50	13				
TEST SETUP	35	7	3			
TOTAL	202	47	5			
NON-DEFECTS						
WITHIN TOLERANCE/WAIVER	21	21	2			
UNABLE TO REPEAT PROBLEM	35	7	1	1		
TOTAL	56	23	3	1		

NOTES: 3 spacecraft, 3 on orbit, 4 years of orbital performance
Experiment TDRs not included

PROJECT A - LOCATION OF TEST DISCREPANCIES

TEST/DEFECT	ELECTRONIC COMPONENTS Part	ELECTRONIC COMPONENTS Workmanship	ELECTRONIC COMPONENTS Design	PROPULSION/STRUCTURE Part	PROPULSION/STRUCTURE Workmanship	PROPULSION/STRUCTURE Design	HARNESS Workmanship	HARNESS Design	TOTAL DEFECTS
UNIT ACCEPTANCE	68	100	167		12	7			354
SPACECRAFT ACCEPTANCE	11	15	25	2	23	2	7	2	87
Integration	(3)	(6)	(12)	(1)	(11)	(1)	(3)	(1)	(38)
First Functional	(3)	(2)	(5)						(10)
Temperature	(2)	(2)	(7)		(1)		(2)	(1)	(15)
EMC/IM	(1)	(1)	(1)		(4)		(1)		(8)
Dynamics									
Post Dynamics					(4)		(1)		(5)
T/V Test	(2)	(2)							(4)
Preship Functional		(2)			(3)	(1)			(6)
Launch Base				(1)					(1)
ON ORBIT			1		1	2			4

PROJECT B - LOCATION OF TEST DISCREPANCIES

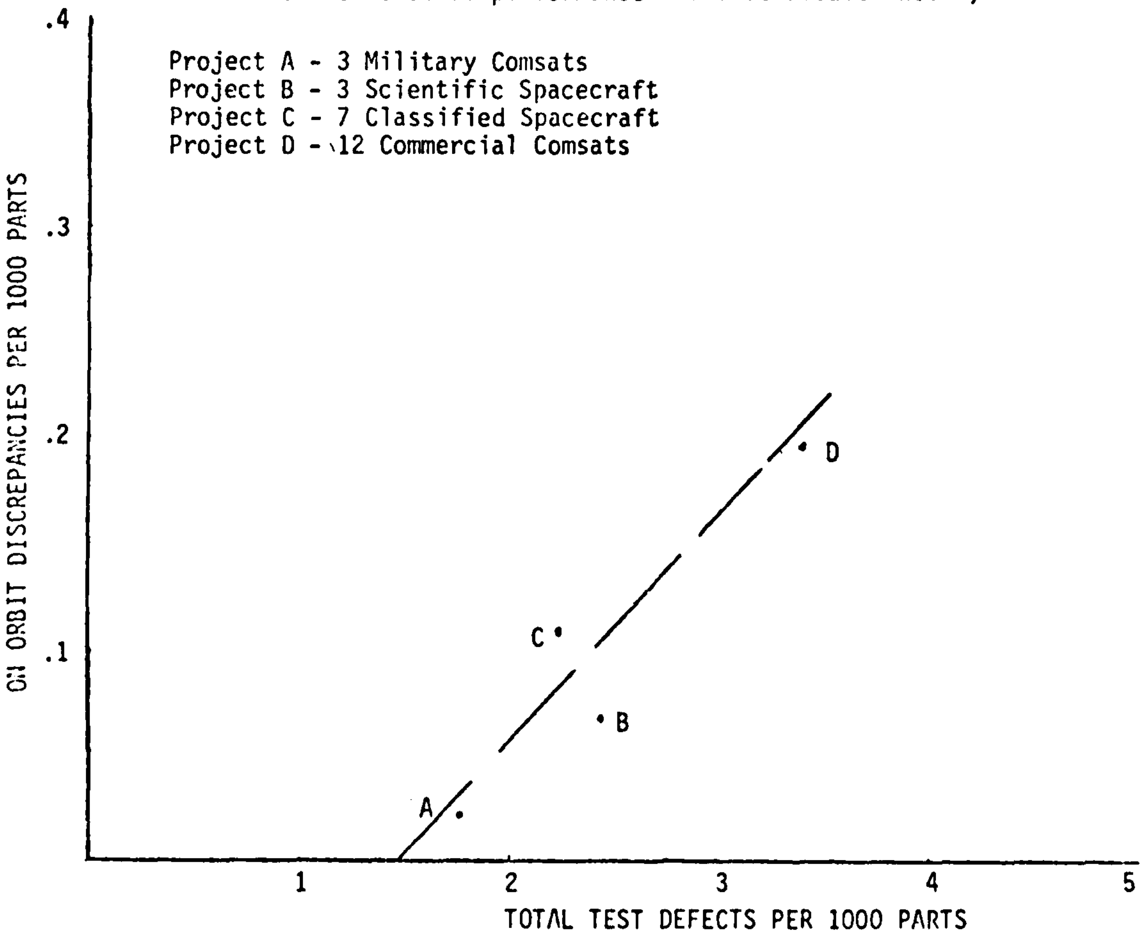
TEST/DEFECT	ELECTRONIC COMPONENTS Part	ELECTRONIC COMPONENTS Workmanship	ELECTRONIC COMPONENTS Design	PROPULSION/STRUCTURE Part	PROPULSION/STRUCTURE Workmanship	PROPULSION/STRUCTURE Design	HARNESS Workmanship	HARNESS Design	TOTAL DEFECTS
UNIT ACCEPTANCE	35	79	43	3		2			162
SPACECRAFT ACCEPTANCE	5	6	23		7	1	11	12	65
Integration			(9)		(5)	(1)	(2)	(9)	(26)
EMC		(2)	(1)				(1)	(1)	(5)
First Functional	(1)	(2)	(4)		(1)		(3)		(11)
Dynamic Environment	(1)	(1)	(1)				(1)		(4)
Post Dynamic Functional	(1)		(2)				(2)		(5)
T/V Environment			(1)						(1)
Preship Functional	(1)		(1)		(1)		(2)		(5)
ETR	(1)	(1)	(4)					(2)	(8)
ON ORBIT	1		5			1			7

PRELIMINARY CONCLUSIONS

- CURRENT TEST PROGRAMS YIELD SUCCESSFUL ON-ORBIT OPERATION. UNDETECTED DESIGN DISCREPANCIES ARE THE PRINCIPAL CAUSE OF ANOMALIES WHICH DO OCCUR.
- A LARGE NUMBER OF COMPONENT DEFECTS ESCAPE DETECTION DURING COMPONENT ACCEPTANCE TESTING AND ARE FOUND BY SYSTEMS TESTS. ABOUT 60% OF SYSTEMS TEST DEFECTS ARE SUCH "ESCAPES".
- ABOUT 2/3 OF SPACECRAFT DEFECTS RESULT FROM INTEGRATION AND INITIAL ROOM AMBIENT FUNCTIONAL TESTING.
- TEMPERATURE CYCLING OF THE SPACECRAFT IS MORE PRODUCTIVE THAN EXTENDED THERMAL VACUUM TESTING.

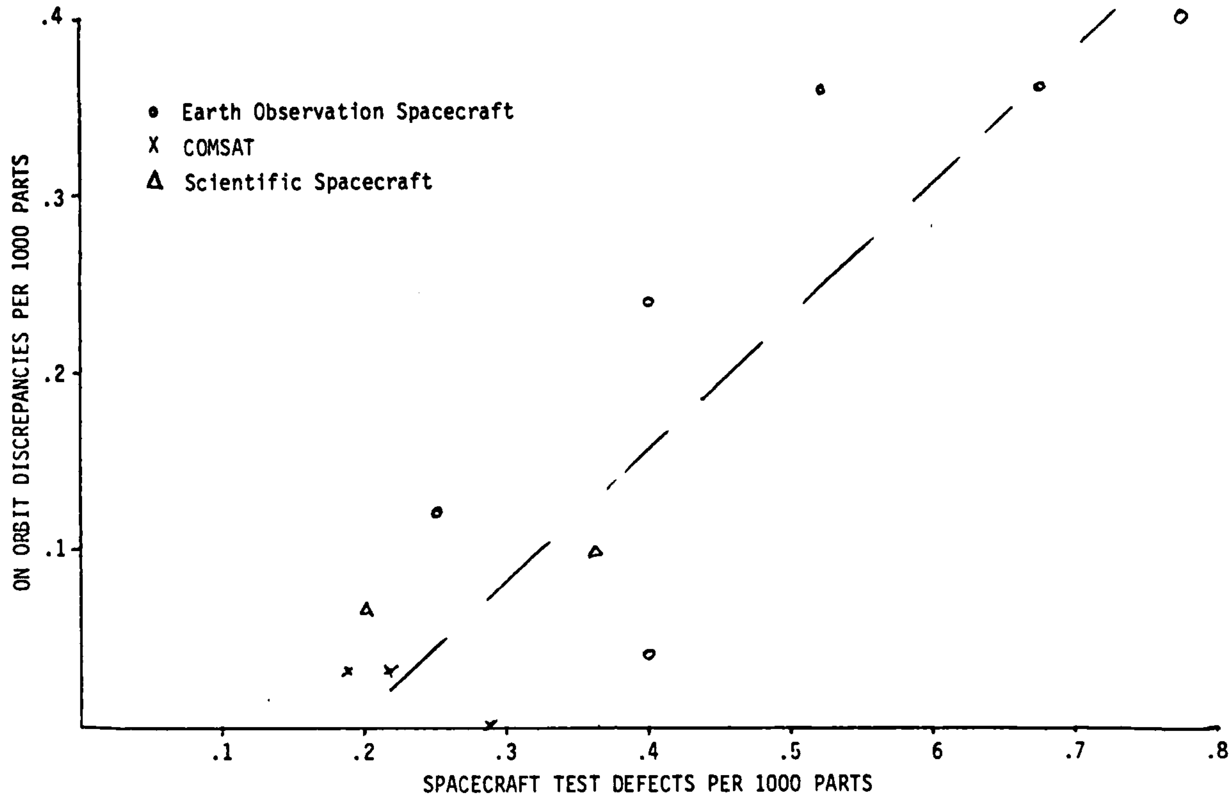
ORBITAL PERFORMANCE CORRELATION BY PROJECT

(Defect rates vary from project to project, but correlation between orbital performance and test results holds)



ORBITAL PERFORMANCE VS. SYSTEM TEST RESULTS

(The system test program finds about 80% of all lifetime spacecraft problems)



SOME RECOMMENDATIONS

- DESIGN TEST PROGRAMS TO FOCUS ON POSSIBLE DESIGN DISCREPANCIES BY CONDUCTING MORE REALISTIC END-TO-END PERFORMANCE TESTS.

- CORRECT DEFECTS AS EARLY AS POSSIBLE SINCE COST IMPACT OF FAILURES AT THE SPACECRAFT TEST LEVEL IS USUALLY AT LEAST 5 TIMES AS GREAT AS AT COMPONENT LEVEL.

- INCREASE THE COMPONENT LEVEL TEST DURATION AND ENVIRONMENTAL STRESS LEVELS TO DISCOVER INCIPIENT FAILURES PRIOR TO SPACECRAFT INTEGRATION.

- PERFORM TEMPERATURE CYCLING TESTS RATHER THAN LONG DURATION T/V TESTS AT THE HIGHEST POSSIBLE LEVEL OF ASSEMBLY SINCE THIS IS MORE COST EFFECTIVE IN FINDING DESIGN AND WORKMANSHIP DEFECTS.

TEST SOFTWARE (SYNOPSIS)

E. W. Dusio
Manager, Software Engineering
RCA Astro-Electronics

This discussion presents several different approaches to test software development and usage at RCA Astro-Electronics and compares them with respect to (1) ease of developing the test programs, (2) ease of debugging the units under test, and (3) ease and throughness of testing. Software development facilities and self-testing software for flight computers are addressed. Some possible topics for further workshop discussion are also identified.

TEST SOFTWARE

- TEST SOFTWARE LANGUAGES USED AS ASTRO
- LANGUAGE CHARACTERISTICS
- TEST SOFTWARE DEVELOPMENT FACILITIES
- SELF TESTING SOFTWARE FOR FLIGHT COMPUTERS
- POSSIBLE TOPICS FOR DISCUSSION

TEST SOFTWARE LANGUAGES USED AT ASTRO

- ATLAS: A SUBSET OF STANDARD ATLAS
- BASIC: HEWLETT PACKARD'S BASIC
- TEST CONTROL LANGUAGES: SEVERAL HOME BREWED VERSIONS

LANGUAGE CHARACTERISTICS

- ATLAS: SOURCE COMPILED TO INTERMEDIATE CODE PRIOR TO EXECUTION
- BASIC: LINE-BY-LINE INTERPRETER EXECUTES SOURCE.
- TCL'S: BOTH COMPILER AND INTERPRETER VERSIONS HAVE BEEN BUILT.

ATLAS AND BASIC LANGUAGE CHARACTERISTICS

- "STANDARD" LANGUAGES
- LIMITED TRANSPORTABILITY TO OTHER SYSTEMS
- VERY FLEXIBLE, CAN EXERCISE ALL TEST EQUIPMENT OPTIONS
- TEST WRITERS REQUIRE NITTY GRITTY KNOWLEDGE OF TEST STATION

TEST CONTROL LANGUAGES LANGUAGE CHARACTERISTICS

- INTENTIONALLY LIMITED FLEXIBILITY
- TEST STEP ALGORITHMS ARE LOCKED IN THE SOFTWARE
- A TEST = A SEQUENCE OF TEST STEPS

TEST SOFTWARE DEVELOPMENT FACILITIES

- SEPARATE DEVELOPMENT FACILITIES WITHOUT TEST BUS AND EQUIPMENT.
  - ONLY A LIMITED TEST OF PROCEDURES IS SUPPORTED
- SHARED TEST/DEVELOPMENT FACILITY
  - THE AVAILABLE TEST TIME IS REDUCED BY DEVELOPMENT TIME ALLOCATION
- ULTIMATELY THE PROCEDURE, TEST STATION AND UUT ARE DEBUGGED TOGETHER

DEBUGGING UUTS WITH TEST SOFTWARE

ATLAS

A MANUAL MODE PROCEDURE CHAINED INTO TEST PROCEDURE ALLOWS KEYBOARD CONTROL OF TEST

BASIC

INSERT DEBUG CMDS FROM KEYBOARD.

TCL

MANUAL MODE BUILDS NEW TEST SEQUENCES FROM KEYBOARD.

THROUGHNESS OF TESTS

THOROUGHNESS OF TESTS IS A FUNCTION OF THOROUGHNESS OF DATA EVALUATION

- A CONTINUOUS BACKGROUND PROCESS MONITORS UNEXPECTED STATE CHANGES OR PARAMETER DRIFTS OR:
- THE DATA IS SAMPLED UPON DEMAND.

IN BOTH CASES HARDWARE FAULT MONITORS PROTECT UUT UNDER TEST

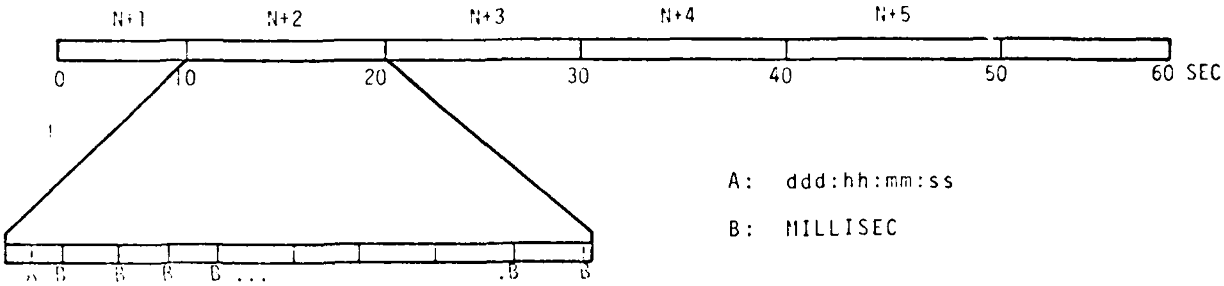
SELF TESTING SOFTWARE FOR FLIGHT COMPUTERS

- [illegible]
- [illegible]
- [illegible]
- [illegible]

TOPICS FOR DISCUSSION

- [illegible] SYSTEM AND SYSTEM TEST [illegible] TECHNIQUES.
- [illegible]
- [illegible] PROCEDURE.
- [illegible] SIMULATORS FOR TEST DESIGN AND DATA EVALUATION, AND TEST SYSTEM VALIDATION

TEST STEP ALGORITHM UPDATE CLOCK



FRAME	
N+1	ACQUIRE CLOCK WORDS FOR REFERFNCE
N+2	COMMAND UPDATE CLOCK, VERIFY NORMAL CLOCK SEQUENCING
N+3	VERIFY JUMP IN TIME TO UPDATED VALUE
N+4, N+5, N+6	VERIFY NORMAL CLOCK SEQUENCING

NOTE: AT ALL OTHER TIMES, A BACKGROUND PROCESS MONITORS FRAME TO FRAME SEQUENCING OF TIME CODE

SUMMARY OF ISSUES AND RECOMMENDATIONS

TEST EFFECTIVENESS

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Test Data Exchange

<u>Issue</u>

There is a lack of data interchange among projects and contractors which would allow better decision making regarding the most productive test procedures at the various levels of assembly and test environments to maximize test effectiveness and reduce overall test costs.

<u>Recommendations</u>

o Establish a committee including AF Space Division, NASA and contractors to provide a continuing forum for exchange of test program data and experiences at the subassembly, component (box), subsystem and system test levels. Related orbital performance results would be included. Significant conclusions would be shared with engineers and project management personnel. Growing complexity at lower levels of assembly makes the need more acute. There is a very strongly and nearly unanimously felt need for this experience sharing forum as a continuing but not overly formalized working group. The Space Parts Working Group was mentioned as a possible model.

2. Failure Information Exchange

<u>Issue</u>

Accumulation of failure information from systems, subsystem and component (box) test programs across many programs is extremely difficult. Summary data is not uniformly or consistently required on contracts. Formats and contents are highly variable. Data base accumulation is needed to examine and validate proposed changes to current test philosophies, approaches and procedures.

<u>Recommendations</u>

o Examine existing industry and government reporting systems and develop a compatible common data requirement (Data Item Description) for use in contracts. Intent would be to accept contractors' formats, so long as certain key information is included.

3. MIL-STD-1540A

<u>Issue</u>

Many changes to the technical requirements now in MIL-STD-1540A have been proposed by both industry and government. In most cases, the data base is, as yet, insufficient to fully support the proposed changes. A major redraft of MIL-STD-1540 is now in progress. Reviews and working meetings are forecast for September-October 1980, with subsequent publication about March 1981.

<u>Recommendations</u>

o Acquire and analyze additional information from component (box), subsystem and system test programs to allow logical and supportable decisions about significant changes in requirements. Update the requirements of MIL-STD-1540 to include those changes and improvements which will improve test effectiveness, efficiency and perceptiveness.

4. Qualification Flight Items

<u>Issue</u>

Test guidance and technical requirements for "buy-one-fly-one", Protoflight or "fly qualification

items" is minimally addressed in MIL-STD-1540A. These approaches are used for various sound reasons by many programs. Test baseline guidance, including technical requirements is needed for these kinds of programs and projects.

Recommendations

- Implement a section(s) in the next issuance of MIL-STD-1540 which covers these areas. A major redraft of the standard is now in progress with a publication target of March 1981.

5. Testability

Issue

Testability of many existing designs is not adequate for evaluation of conformance to performance requirements and identification of discrepancies through testing at component (box), subsystem and system levels, nor for analysis of orbital performance anomalies. Newest technologies (hybrids, VLSI, etc.) compound the problem. Testability must be an "up-front" requirement, demanded and addressed from the earliest program phases onward.

Recommendations

- The customer should require adequate attention to testability approaches, philosophies, and design features from program inception onward. Testability design features should be address ed in the RFP and proposals, with subsequent review and approval of their implementation throughout the development cycle. There is no "Royal Road" to testability, but rather there are a number of approaches and techniques which are appropriate for various technologies and program trade-offs.

6. Automated Testing

Issue

Automated test requirements forecast to be increasing at an exponential rate due to increasing system complexity and technology changes. Automatic testing techniques, configurations, software languages, etc. have also been "exploding". A forum for customers, contractors and Automatic Test Equipment manufacturers is needed which will recognize the concerns and needs of the space systems community.

Recommendations

- An effort similar to the industry/joint services automatic test project should be accomplished, with a subsequent continuing foru forum to be established. The con concerns for automated testing of space systems are not necessarily different from those of other services or industry segments, but do appear to have different urgency levels for some problems, due largely to the few-of-a-kind but extremely complex nature of the systems involved. Governmental or major industry association sponsorship is seen as necessary.

7. Testability in Design

Issue

Many automated test systems (ATS) are developed under extreme cost, schedule and resource constraints-to meet program needs and limitations. This is true both for program unique ATS and for hardware/software interfacing to common ATS. Growing test requirements magnify the problems and program risks in cost, schedule and resources. ATS is or will be a major program concern and should be addressed as such.

Recommendations

- Automated test systems personnel must be involved as early as possible in concept, RFP, proposal and design development. Deferral assures later problems and detrimental compromises.

- Project/Systems management approaches need to be more widely implemented in the ATS arena to assure better program-ATS compatibility and more effective and efficient ATS acquisitions.

- The automated testing area needs greater emphasis in RFP, SOW, proposals and contract management too l (WBS for example).

8. Test Language

Issue

The lack of adequate high level test languages is adversely impacting test costs, schedules, resources and effectiveness. As spacecraft complexity increases, and the impact of not having adequate computer languages for automated tests is further magnified.

Recommendations

- Investigate, define and develop a high level test language for use on automated test systems. NASAs "STOL" system test language should be examined for system test applications. Current language standardization efforts do not appear to offer any relief for the spacecraft test language problem, at least not in the reasonably near term.

WORKSHOP E

E-1 PARTS – THE MANAGEMENT AND PROCUREMENT OF PIECE PARTS

Chairmen	**Coordinators**
Lt. Col Kenneth Blakney Chief, Technical Management Div. AF Space Division	J.F. Wiesner The Aerospace Corporation B. Evans, TRW
Robert C. Karpen Manager Parts and Materials Division of Program Assurance, NASA HQ	
Dale M. Cole Project Leader Advanced Components Engineering General Electric Co. - AESD	
AF Space Division Activities	Lt. Col. Blakney AF Space Division
NASA Parts Activities	R.C. Karpen, NASA
Overview of Space Parts Market Place	John Shea, ICE
Supplier Overview of Space Parts Procurement	R. Lambert Signetics
Small Volume Procurement Implementation	D. Cole, GE/AESD
Coordinated Procurement	Paul Dick, GE
Managing, Development & Procurement of LSI and Hybrid Space Parts	C. Murphy, RI W.R. Scott, JPL

USAF SPACE DIVISION
SPACE PARTS ACTIVITIES

Lt Col Ken Blakney
USAF Space Division

Space Division (SD) is committed to improving the reliability and availability of all the parts used in the spacecraft and launch vehicles managed by SD. This short presentation will summarize (1) the reasons for that commitment, as well as (2) Space Division activities (past, present, and planned) that are aimed at developing standard space quality parts, requirements, techniques, documents, and sources and making space quality parts available for use by all space programs. I will also briefly discuss the problems and challenges we face. We hope that the discussions of this workshop will bring these challenges into better focus and formulate some implementable recommended solutions to those challenges which we have not already solved.

In trying to clarify the issues and formulate solutions to the "parts problems" confronting us, we must keep in mind the unique features of the systems (spacecraft and launch vehicles) and situation we are addressing.

a. Spacecraft and launch vehicle contract "buys" generally consist of less than ten systems or subsystems and entire spacecraft programs often involve only two, three, or four spacecraft. Thus, statistical sampling and learning curves are not very useful for achieving spacecraft reliability. We must, instead, rely on "up front" engineering, failure prevention, and doing it right the first time.

b. Because of the evolution of program mission requirements, rapidly changing technologies, and the autonomous nature of each program/prime contractor combination, each spacecraft "set" generally is, at least partially, unique in its design features. Once again, the learning curve and reliability growth have limited applicability. We must, instead, maximize the use of lessons learned and standard parts, techniques, and documents in order to translate the successful practices from one program to another.

c. Because we are unable to remove and replace field items in orbit, we must design and fabricate our spacecraft from the most reliable parts, materials, processes, and design features available to prevent premature failure of the system.

d. "Replacement" of a failed spacecraft or launch vehicle involves multi-million dollar funding and a significant percentage of program dollars, schedules, and equipment assets. Our approach, therefore, must be to take no shortcuts that would increase the risk of premature system failure.

Spacecraft reliability requirements have become increasingly difficult to achieve because of (1) increased lifetime requirements and (2) increased system complexity and part count. As shown below, SD spacecraft have evolved from required Mean Mission Durations (average expected time to failure) of 12 and 18 months to required Mean Mission Durations of 7 years (84 months). At the same time, these systems have increased in complexity more than 15 fold. It is encouraging to note that selected SD spacecraft have achieved successful operation on orbit of 5½, 6+, and 9 years. To date, however, the average time to failure of SD spacecraft is less than 5 years. If we are to achieve the desired MMD of 7 years, we must, therefore, improve the reliability of the parts used to design and build our current and future spacecraft.

	MMD Required (Months)	Electronic Parts
IDCSP	18	4,700
DMSP, Block 4	12	10,000
DMSP, Block 5A/B/C	5.2	23,600
NATO II	36	12,900
DMSP, Block 5D	19.7	25,000
DSCS II	36	36,000
NATO III	56	21,000
FLTSATCOM	37	60,000
GPS, PHASE I	48	33,500
DSCS III	84	150,000
GPS, PHASE III	72	TBD
STRATSAT	84	TBD

	No. Op.*	MMD Achieved (Months)	Longest Life(Months)
IDCSP	0	73	108
DMSP, Block 4	0	13.7	25.6
DMSP, Block 5A/B/C	0	16.1	39.8
NATO II	0	45.5	66
DMSP, Block 5D	1	20.7	31.2
DSCS II	7	22.7	76 +
NATO III	3	36	48 +
FLTSATCOM	3	12.1	24.4+
GPS, PHASE I	5	15.9	24.5+
DSCS III		TBD	
GPS, PHASE III		TBD	
STRATSAT		TBD	

*Satellites still operating may increase MMD
+This particular satellite still operating

Space Division's launch vehicle reliability record is very good. The success ratio of over 280 launches over the past 15 years is 95%. We require, however, that our new launch vehicles achieve 96% to 97% reliability. And due to the enormous cost of replacement of launch vehicles and their payloads, we desire and strive for 100% reliability.

These system requirements and constraints are reflected into the parts level requirements and constraints. Since a spacecraft is composed of more than 100,000 parts, mostly electronic, and since a single part can cause failure of the entire spacecraft or mission, every part must be of the highest reliability attainable. Redundancy can help alleviate this situation, but due to system weight constraints, redundancy is limited and is usually not practiced at the part level. Also, redundant unreliable parts will certainly not allow achievement of 7 year spacecraft lifetimes.

Since the 1978 Mission Assurance Conference, we have made considerable progress toward development of standard "space quality" requirements, specifications, test methods, and other improvements in the reliability of parts used in our space systems. Space Division programs are still, however, experiencing difficulties in procuring parts of sufficient reliability to support program requirements. Small quantity parts buys, divergence of space requirements from available "commercial" parts, rapidly changing LSIC technology, and resultant part manufacturer lack of interest in small quantity, "special" space parts are some of the underlying causes of the parts procurement difficulties. The ultimate results of our inability to procure readily available "space quality" parts include program schedule slips, redesigns and part retrofits, cost overruns, and compromises in the part and program reliability.

The following list summarizes the highlights of the parts panel conducted at the 1978 Mission Assurance Conference. That conference set the tone and direction of the Space Division space parts program activities of the past 2 years. The remainder of this presentation will report the current status and planned direction of the Space Division space parts program.

Parts Panel Highlights

a. Piece part reliability critical to space system mission success
b. Program part reliability problems

(1) Significant part failure/ yield problem
(2) Program peculiar spec. requirements
(3) Lack of available standard space quality parts

c. More comprehensive parts management required
d. Newly published SAMSO parts policies
e. DESC committed to standardization of Class S specs/parts
f. Well managed coordinated procurement offers advantages
g. Joint SAMSO/NASA/DESC Class S approach being implemented
h. Class S program needs acceleration to support programs

First, however, so that we are all working from a common baseline, I will summarize the objectives of the SD Space Parts Program activities. These objectives are stated in their order of importance to SD missions, although most of the individual efforts and products satisfy, at least partially, more than one of the

listed objectives.

a. Improve parts reliability

(1) All part types
(2) Reduce/prevent failures/causes
(3) Standard space quality (Class S) documents and parts
(4) GSI/CSI

b. Improve availability of space quality parts

(1) Standardization on parts and requirements
(2) Line certifications
(3) MIL QPL (Class S)
(4) Coordinated procurement

c. Improve parts management techniques and implementation

d. Reduced program costs

(1) Reduced failures
(2) Spec writing/negotiations
(3) Qual tests
(4) Process problems/yields
(5) Retest/rework
(6) Schedule slips

The Space Division approach to improving reliability and availability of parts for space system application includes the following elements:

a. Extensive management by each program and prime contractor of all parts used in the system. This includes implementation of standard part management program requirements and techniques.

b. Development and implementation of standard "space quality" technical (specification and application) requirements for all standard and non-standard parts. This includes standard test methods and identification and prevention of all part failure causes.

c. Development of standard Class S (space quality) military parts, specifications, certified lines, and qualified products lists.

d. Development and implementation of requirements and methods for part procurement that are applicable to the small quantity, space quality parts buys typical of space programs.

e. Maintaining the Space Parts Working Group as an SD/NASA/Government Agency/Industry "Space Part Users" committee to formulate, coordinate, interchange, and assure integration of space parts activities and products for improving the reliability, availability, and cost effectiveness of space parts.

The joint SD/NASA/DESC/RADC approach to developing Class S Military Standard parts and sources is summarized below. This approach was presented and endorsed at the 1978 Mission Assurance Conference and has been subsequently applauded by the Space Division Advisory Group on Electronic Reliability.

a. Identify/coordinate candidate parts/types
b. Develop joint Class "S" (space quality) requirements
c. Incorporate Class "S" requirements into MIL Specs
d. NASA/SD/DESC certifications
e. DESC/NASA/SD Class "S" MIL qualifications
f. SD/NASA preferred parts lists
g. SD/NASA/DESC baseline control

SD Space Parts Program Status

The current SD Parts Policies are those policies developed just prior to the 1978 Mission Assurance Conference:

a. Select/procure Class "S" parts if available
b. Prime contractor conduct coordinated procurement
c. Monitor manufacturer processes
d. Assure all program parts meet program reliability goals

When MIL-Standards 1546 and 1547 are published, we will expand these parts policies to include implementation of parts program management and standard technical requirements per these two documents.

MIL-STD-1547 (Standard Technical Requirements for Contractor Specified Parts) is very near to publication. These requirements were developed by SD/AQT, Aerospace Corporation component experts, and the

Space Parts Working Group. They include additions or modifications to preferred MIL Spec requirements and are based on lessons learned and failure preventions from previous/current space programs. These standard requirements will soon be implemented by all new Space Division programs.

Summarized below is the progress made in the availability of Class S microcircuits. Other certifications and qualifications are in progress. Filling out the Class S QPL has been slow due to uncertainty of the market, infrequent new starts (programs), and the shift from SSI/MSI to LSIC and hybrids.

a. MIL-M-38510 (Class S requirements) published
b. Class S MIL-STD-883 test methods published
c. MIL-STD-976 (cert requirements) published
d. 7 certifications complete
e. 3 certifications in progress
f. Hardness assurance test methods published
g. 108 part numbers on Part II QPL
h. Class S qual effort needed

The status of JAN S semiconductors follows. Again, qualification is the current hurdle and we plan to try to accelerate the JAN S certifications and qualifications in the next few months.

a. MIL-S-19500F (JAN S requirements) published
b. JAN S MIL-STD-750 test methods published
c. Certification requirements published
d. Motorola small signal diode line certified
e. JAN S qual needs acceleration

The following summarizes the status of the highest priority Class S passive spec projects. These efforts will receive increased manpower and attention for the remainder of this fiscal year.

a. Ceramic capacitors - MIL-C-87151 (NASA) - CKS

(1) Final draft in coordination

b. EMI filters

(1) SD/NASA spec being merged with Navy/DESC spec

c. Relays (0-25 amps)

(1) Draft Class S spec in work by SPWG subcommittee

d. Thermal switches - MIL-S-24236

(1) Draft Class S appendix to MIL Spec in work

e. MICA Capacitors (MIL-C-39001)

(1) Draft changes to MIL Spec in work

f. Solid tantalum capacitors (MIL-C-39003)

(1) NASA/Crane testing in progress

g. Metalized film capacitors - MIL-C-83421

(1) NASA/SD preparing changes to MIL Spec

The SD Preferred Parts list have been revised, the Class S Part II QPL microcircuits added, and recently published as SD-STD 73-4B. When MIL-STD-1546 is published, the SD PPL will be appendices C and D thereof.

When published, MIL-STD-1546 (Parts Program Management Requirements for Space and Launch Vehicles), along with MIL-STD-1547, will replace SAMSO-STD 73-2C.

MIL-STD-1546 expands and clarifies the Parts Program Management Requirements of SAMSO-STD 73-2C and includes implementation of SD Parts Policies, Coordinated Procurement requirements, part application requirements, and the SD Preferred Parts List. Since MIL-STD-1546 is a Management Control System, it must be sent to DOD/MIAG for review. Publication is expected prior to 1 August 1980.

Coordinated Procurement (by the Program Prime Contractor) of electronic parts, particularly microcircuits and semiconductors, has been a Space Division policy for the past two years. Implementing requirements are about to be published in Appendix A to MIL-STD-1546. SD programs (DSCS III, IUS, AMARV, and ABRV) have implemented tailored versions of coordinated procurement and have achieved cost and schedule benefits. Coordinated parts procurement offers advantages for cost, schedule, and reliability if adequately planned and well managed. Papers and discussions at both the previous Mission Assurance Conference and this workshop explore recent experiences in implementing various forms of coordinated procurement, advantages and benefits achieved, and implementation difficulties. Better definition of and alternatives to Coordinated Procurement is one of the three principle discussion topics of this workshop.

Government Source Inspection is one of the features of the MIL-Spec standard part system. The Class S requirements include specific GSI inspections as a condition of JAN marking the parts and releasing the lot for delivery. These requirements are contained in MIL-M-38510D, MIL-S-19500F, and other "Class S" MIL specs. The detailed delegation of the MIL-M-38510D GSI inspections is currently in review by DLA and is expected to be published/implemented in the near future.

Contractor Source Inspection of non-Class S parts is required by MIL-STD-1546. A better definition of the specific CSI requirements, by part type, is currently planned for development by SD/Aerospace and the SPWC this summer.

At the 1978 Mission Assurance Conference Microelectronics Workshop, Large Scale Integrated Circuits and Custom Hybrid Microcircuits were identified as "new" part types finding increasing application in space systems. Because of their increased complexity, lack of maturity, incomplete testability, divergence between commercial LSIC and space LSIC requirements, and custom circuit development risks; large scale integrated circuits represent a significant new reliability risk to space systems and therefore require accelerated effort to develop Class S requirements, new test methods, design rules, more complete characterization, information exchange, procurement techniques, standardization, and technology developments.

Since the 1978 Microelectronics Workshop, Space Division and Aerospace Corporation have increased their activities to define and develop space quality LSIC.

a. The LSIC committee of the Space Parts Working Group was formed and is proceeding in the development of LSIC requirements definition, alternate screen tests, improved testability, and other LSIC improvements.

b. The LSIC section was added to the SD Preferred Parts List.

c. SD/Aerospace have participated with RADC, JPL, and others in the development of MIL-STD LSIC slash sheets.

d. Three part manufacturer lines that produce LSIC memory devices have been certified to Class S requirements.

e. We have participated with RADC in improving characterization of selected MIL-STD LSIC.

Custom Hybrid Microcircuits were also a principle discussion topic at the 1978 Microelectronics Workshop. Like LSIC, these devices offer weight and performance advantages but can also introduce cost, schedule, and reliability risks. The 1978 Conference scoped the Hybrid situation and recommended we get on with development of Class S requirements. The SPWG Committee on Hybrid Requirements was already in the first stages of the task at that time.

Today, we are nearing completion of Class S requirements for Custom Hybrid Microcircuits. MIL-STD-1581, which contains these requirements, is currently in review by the Space Parts Working Group. When completed, this document will be integrated, if possible, with NASA and RADC (Singer) prepared documents addressing Custom Hybrid Microcircuits. Also, since the DSCS III program used many custom hybrids, the experiences and lessons learned of that program will be summarized for use in refining our requirements and approaches.

One of the principle topics of this workshop will be approaches and recommendations for adequate management of LSIC and custom hybrid microcircuits. Valid recommendations, from whatever source, will be coordinated and included in MIL-STD-1546.

There is much more work to be done to define and develop standard approaches and requirements for LSIC and Hybrids. SD and Aerospace intend to devote increased resources and emphasis to these tasks. We hope that this workshop and subsequent SPWG activities will better define the tasks, practical solutions, and specific requirements associated with acquiring space quality LSIC and custom Hybrid microcircuits.

Some of the remaining challenges to achieve space quality in all part types and improve space mission reliability are listed below. This workshop should help define and prioritize the recommended solutions to these and other challenges surfaced here. SD, Aerospace, and the SPWG are dedicated to refining and implementing these and other recommended solutions for the benefit of all space missions.

a. Longer required spacecraft lifetimes
b. Increased system part count and part density
c. Rapid completion of Class S documents
d. Building Class S QPL(s)
e. Defining the "Class S" market
f. Defining/implementing GSI/CSI and other "policing" methods
g. Developing implementable "back-off" approaches
h. Validating reliability of new technologies
i. Developing "Class S" technical and management requirements for LSIC and Hybrids
j. Consistent implementation of "Class S" requirements
k. Improving cost/delivery times for "Class S" parts
l. Resolving SD/NASA parts approach divergences
m. Improving flow down of parts requirements to subcontractors

NASA PARTS MANAGEMENT

Robert C. Karpen
Manager Parts & Materials
Office of the Chief Engineer
NASA Headquarters

NASA parts management has evolved and grown over the past twenty years and there is more growth and change coming. I will not dwell on our past but the main change has been from a solely technical concern to an expanded involvement in parts management.

To prepare you for our walk through the NASA parts management system, let's first do a little roadmapping as to the players and documents involved. (First Chart)

There are five management functions that I will describe with respect to this abbreviated organization chart:

- o Policy Coordination
- o Policy Surveys
- o NASA Parts Steering Committee
- o GIDEP/Alerts
- o Standard Parts Program

Policy concepts originate at various sources within and outside of NASA. Usually they are submitted to the appropriate cognizant office which will draft and coordinate the policy. Most of the parts management policies are derived from R&QA policies or recommendations of the NASA Parts Steering Committee. The extent of coordination depends on the subject and number of officials assigned responsibility. There are two levels of policy; one that is NASA-wide and one at the Center level, even at Headquarters. Consequently, each Center can implement parts policy differently as long as the Center-level policy is not in conflict with the NASA-wide policy.

Periodic surveys of the Field Installations are conducted by Headquarters to assess Center conformance to NASA and Center level policy. The Chief Engineer's Office surveys Program Assurance activities at Field Centers every two years. Special surveys are conducted in the field and at contractor plants as needed.

Originally, the NASA Parts Steering Committee was formed to exchange parts information and resolve technical problems. Parts management problems and techniques are appearing more frequently on the agenda. Each Field Center has a representative as do most Program Offices at Headquarters. Parts policy concepts are formed and debated by this Committee. The policy development typically is tasked to its chairman - myself - for coordination and implementation. Three of the policies, that have been implemented, concern data exchange, problem reporting and standardization. They define NASA participation in GIDEP*, the Alert Problem Reporting System, and the NASA Standard Parts Program.

(Chart 2) The Standard Parts Program has been established to promote the use of standard EEE parts. A Lead Center Office was established at Marshall Space Flight Center (MSFC) in the R&QA Office and operates the program with technical

*Government Industry Data Exchange Program

support both from within MSFC, from other Centers, Naval Weapons Support Center and test and engineering support contractors. The office is responsible for implementing standardization projects and coordination activities with other NASA Centers, DOD and industry.

Next, a quick look at the principal policy documents influencing parts management within NASA. (Chart 3) One of the basic controls is the Reliability and Quality Assurance policy. Through it the requirements documents in the NHB 5300.4 series have been developed (Chart 4). It is required by our procurement regulations that these requirements, be reviewed and included as contract requirements, as appropriate. Special policy and Project requirements also been developed for special situations. For example, NHB 5300.4(1D-2) for the Shuttle Program, NMI 8010.1 Classification of NASA Space Transportation System Payloads, and special parts lists and control documents for projects.

Referring back to a previous chart, (Chart 3) you'll note that there is no direct tie from our standardization policy through our procurement regulations to our contracts. New parts policy drafts are in process to implement this and other, more recent, parts controls which are not contained in the NHB 5300.4 series.

BASIC PRINCIPLES

What are some of the basic principles we use in the NASA parts program? One is "Don't Reinvent the Wheel!". We can't afford to. There are many examples where we share information. There are problem reports, experience bulletins, test reports, calibration procedures, specifications, standards, test methods, guidelines and on, and on. Cost sharing is also important in the services area. We share services, such as DCAS and AFPRO at our contractors sites, DESC for specifications and standards, and the Navy publications capabilities. There can be problems with other people's documents and services. They can't be blindly applied to any new situation. There are many times that they will have to be modified to make them so they are more palatable when you're bucking a "not-invented-here" or "not-in-our-format" syndromes.

The second principle is also an attempt to hold down the costs. We advocate the selection of parts on the basis of minimum overall project cost to NASA, not just the front-end cost as listed in the parts vendors catalog. It's not easy. High reliability parts are expensive. Use of established aerospace contractors in-house spec systems has its advantages. The use of commercial parts and rescreening appears cheap. What we need is more data, like a Goddard Space Flight Center evaluation two years ago of Class A versus Class B versus commercial parts in terms of

total cost but also with probable success estimates. It can show project managers, and I think parts people, the relative cost at each point and net impact of their selections. This need for assessment is not only true in the part quality/reliability areas but in parts procurement techniques and project schedules. Programs are starting to release funds earlier to permit purchase of long lead items. The NASA project manager is still the prime decision-maker on hardware and is given a fair amount of leeway in his pursuit. The expanded documentation and data is geared toward helping him make the assurance decisions. How often did you hear that designing with military parts is designing with obsolete parts? We're caught in an unusual, and I think fantastic, electronics evolution. I don't want to stymie creativity and innovation. But, let's use the edge-of-technology devices where they are not critical. The designers are trying to hurry the new devices into the hardware. We're trying to hurry the cycle, too. Through the Standardization Program we are helping mature new technologies by characterizing and documenting early in their development. Our independent product evaluation has resolved design errors sooner than if we had waited for the design to stabilize on the commercial market. In spite of their complexity, I believe the microprocessors are getting specified faster. In addition to the products, we are starting to scrutinize test methods better and we'll be analyzing parts management techniques so that there is a shorter trial and error period.

The last principle is the old "Don't bite off more than you can chew". We've been evolving into a parts program over several years. It started by concentrating on the microcircuit devices, later expanded to most EEE parts, and is expected to spawn an equivalent materials program soon. But as we have evolved, we have been maintaining the many facets that we have developed. So many good ideas have fallen by the wayside because it's more fun to create concept than to maintain it. Maintenance is hard to support when priorities tend to shift alot. We are trying to handle those shifts by also remaining flexible.

WHAT'S MISSING

Here are some of the areas we'll be working on and a couple that are still problems. We are developing stronger management of the parts program. It has grown to the point where better visibility and controls are needed to keep it efficient. We are building a parts usage data base to forecast trends and establish priorities.

Hopefully, we can centralize parts problem reporting to effect fundamental corrective actions to specs, standards and procedures when needed. I think we need better visibility of NASA procurement of Class S level parts and the effectiveness of the new payloads policy.

We will start looking at ways to more accurately define

what we really need. Better evaluation of new test methods, assembly methods, and management techniques to determine their risks and effectiveness. What are good techniques to get realistic user requirements? A related area is establishing priorities among the multitude of tests, evaluations, documents, etc. Priorities used by different organizations vary for obvious reasons. Some of our conflicts in the parts program are:

- o Grade 1 versus Grade 2 development
- o Help small quantity or large quantity user
- o Build in reliability versus screening out defects

As my last comment, let me toss out a thought that might get us a stock of qualified parts. Where are the spare parts from many of our cost-plus programs. Can they be made available? Could we have an initial phase that would list spares and their source, a second phase with a central repository and that could be followed by a replenishment program; that sounds like stocking by another name.

ORGANIZATIONAL RELATIONSHIPS

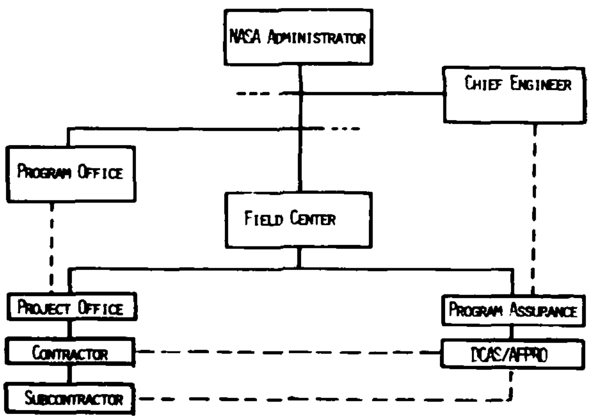
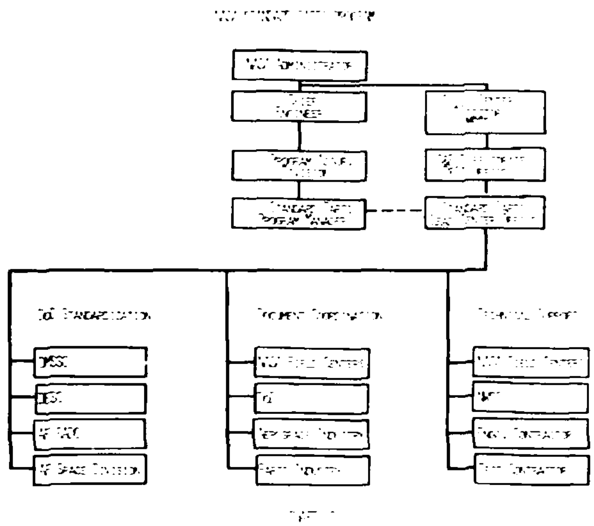
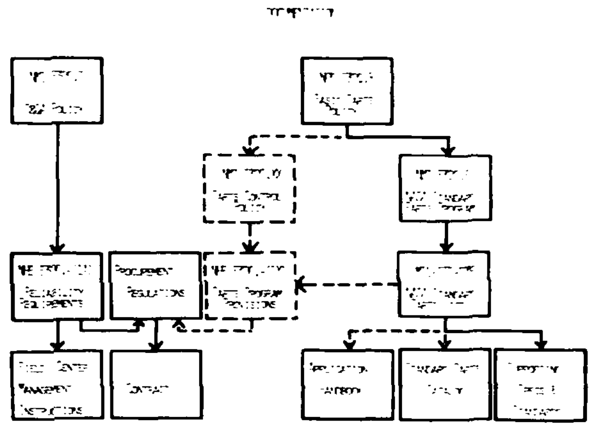


CHART 1





NASA RELIABILITY & QUALITY ASSURANCE MANUAL

VOLUME 1 - GENERAL PROVISIONS

RELIABILITY PROGRAM PROVISIONS FOR AERONAUTICAL AND SPACE SYSTEM CONTRACTORS	NHB 5300.4(1A)
QUALITY PROGRAM PROVISIONS FOR AERONAUTICAL AND SPACE SYSTEM CONTRACTORS	NHB 5300.4(1B)
INSPECTION SYSTEM PROVISIONS FOR AERONAUTICAL AND SPACE SYSTEM MATERIALS, PARTS, COMPONENTS, AND SERVICES	NHB 5300.4(1C)
SAFETY, RELIABILITY, MAINTAINABILITY AND QUALITY PROVISIONS FOR THE SPACE SHUTTLE PROGRAM	NHB 5300.4(1D-2)

VOLUME 2 - GOVERNMENT AGENCY PROVISIONS

MANAGEMENT OF GOVERNMENT QUALITY ASSURANCE FUNCTIONS FOR SUPPLIER OPERATIONS	DRAFT - NHB 5300.4(2A) (FORMERLY NHB 5330.7)
QUALITY ASSURANCE PROVISIONS FOR GOVERNMENT AGENCIES	NHB 5300.4(2B)

CHART 4

MILITARY/AEROSPACE MARKET

John D. Shea

INTRODUCTION

Over the last eighteen months, the military needs for advanced high-technology solid-state integrated circuit devices has become focused before the public eye.

Because of the continued debate with regard to the ratification of the SALT II Treaty by the Congress of the United States, a definite question remains as to whether the continued discussions between the United States and the Soviet Union will act as a diplomatic breakwater to limit the spread of high-technology weapon systems.

The Department of Defense planners are realizing that LSI solid-state integrated-circuit devices will continue to become a key element in force multiplication. The need for real-time numerical generation, computation, signal processing, and sensing is taxing existing silicon technology.

The emphasis placed by the USSR on satellite space weaponry systems for reconnaissance secured communication, 2nd tatical deployment of nuclear warheads for reentry at selected targets on earth, has created a need for closer cooperation between the Department of Defense (DoD), the industrial community, & the academic environment within the United States. (See Table 5-1)

With the realization of advances in Soviet technology, as experienced by analysis of equipment captured by the Israelis during the 1973 Yom Kippur War, it became evident that the Soviet Union had reached near parity with the United States in key technological areas of infrared detection and sensing, as well as sophisticated utilization and application of high-technology IC devices.

Key areas receiving continued attention from the Department of Defense and supported by selected semiconductor manufacturers and prime military/aerospace systems manufacturers are:

A) VHSIC (very high-speed integration IC devices)

B) Radiation-hardened technology for IC devices

C) CCD (charge-coupled) IC imaging devices used for infrared detection, secure communication satellites and spy-in-the-sky satellites.

The Soviet Union has supplied to representatives of Control Data Corporation examples of Soviet semiconductor devices that were direct copies of U. S. products. It becomes apparent that even if these devices were laboratory experimental units, the Soviets have the

ability, if they so desire, to apply resources, manpower, and funding to compete aggressively in the military/aerospace environment with solid-state technology. The Soviet advances in MIRV warhead satellite missile-dispensing systems already in place in orbit around the earth, as well as the Soviets' continued sophistication in reconnaissance satellites, make it apparent that the United States has no recourse but to allocate the necessary funding and resources to assure maintenance of parity and its technological superiority.

Several key programs are underway within the Department of Defense & will be reviewed this section. The VHSIC program is the cornerstone of the ability of the United States to use solid-state devices as a force multiplier, allowing battlefield commanders to make real-time tactical decisions affecting spaceborne, airborne, shipborne and landborne forces. In the area of radiation-hardened devices, several companies such as Lockheed, Rockwell, Hughes Aircraft, National Semiconductor, and Harris Semiconductor have been engaged in productive research to harden aerospace weapon systems.

The manufacturing technology program supported by the Navy, Army & Air Force with regard to the "electronics wedge" scoping will take advantage of advanced state of the art wafer-processing technology. The completely computer-controlled automated factory is one possible result of this program. This facility would provide multiple-technology wafer processing under computer-controlled, minimal contamination environments to manufacture high-density complex integrated circuits of the highest level of field reliability and integrity.

Never before in the history of the United States have strategic military implications with regard to national security been more dependent on the design, manufacturing, and application of high-technology integrated circuits as now. Table 5-2 reviews the U. S. semiconductor manufacturers' support of DoD/Aerospace programs & technologies.

THE VHSIC PROGRAM

INTRODUCTION

The DoD has initiated a major new program in high speed, high throughput signal and data processing in support of the requirements for military systems in the mid-eighties & beyond. The program title is Very High Speed Integrated Circuits (VHSIC) which emphasizes its significant relationship to the technology of ICs as well as the need for higher speed processing capability.

Successful completion of the VHSIC program will enable the DoD to: provide critical electronic subsystems required

to meet military shortcomings expected in the mid-1980's and again in the early 1990's, retain & extend the US technological leadership in advance military electronics; reduce life cycle costs associated with military electronics systems; and avoid a severe future problem in utilizing advanced ICs in military systems due to the fact that they will be either not available, not affordable or both, or not meet military specifications.

VHSIC - Acronym for Very High Speed Integrated Circuits. This acronym was developed to describe the program to develop very large scale integrated circuits applicable to the DoD needs, particularly very high speed signal processing. The speed-density product figure-of-merit goal is 10^{13} gate-Hz/ cm^2. The acronym is also used to describe the integrated circuits that will be developed under the program.

Background

The initiation of the VHSIC program represents a major reversal of past DoD policy to depend on industry to develop needed ICs. Present judgment is that industry is not presently oriented towards meeting the DoD's current & future needs. The industry trend is directed towards very high volume commercial applications, thus permitting high initial design costs to be written off over many production units. The DoD market now constitutes about seven per cent of the US total IC market.... with many low-volume applications requiring the ultimate in performance. The industry trend is toward general-purpose ICs to be used in commercial data processing and consumer applications. It is not sufficiently oriented toward qualifying ICs for military specifications or toward developing ICs with clock speeds sufficiently high to perform current and projected real-time, high-speed signal processing functions. Furthermore, in contrast to many commercial applications, on-chip self-test, self-check, and fault-tolerant techniques are important needs to provide acceptable logistics costs to the military.

The VHSIC program differs significantly from the broad commercial VLSI thrust in integrated circuits in the following major respects:

1. There will be major emphasis on IC development for broad classes of military systems--to develop technology and deliver products for which there is no comparable commercial or industrial need;

2. There will be major emphasis on achieving new architectural concepts which will minimize the need for design customization and hence reduce costs in design, supply & logistics;

3. There will be major emphasis on increasing real-time system throughput,

higher chip complexity and higher clock rates to achieve a capability for real-time signal processing.

4. There will be major emphasis on military environmental requirements such as performance over a high temperature range, radiation exposure and reliability. There will be exploitation of the higher chip complexity available to achieve on-chip and fault tolerance with significantly improved reliability and mean-time-to-repair. Emphasis is placed on high speed signal processing applications having considerable compatability with commercial data processing. All of the VHSIC efforts will take advantage of the leverage provided by the larger commercial VLSI activity but will concentrate on those technology tasks essential to achieving military goals.

Program Description

To meet the above DoD objectives, the program is divided into four parts: Phase O, I, II, and III, each with distinct and important goals. The end goal of the entire program is to reach a capability for advanced systems performance based on availability of ICs with submicrometer feature sizes. Phase O, I & II will be carried out consecutively, while Phase III will be carried out in parallel with Phases O, I, and II.

Phase O- Refers to the program part called "Program Definition" to provide a plan and approach for Phase I and II. (See Table 3)

Phase I - Refers to the program part oriented: (1) to the construction of electronic brassboard subsystems by about 1983 using VHSICs based on 1.25 micrometer minimum feature sizes; and (2) to carry out initial work for achievement of VHSICs based on submicrometer feature sizes.

Phase II - Refers to the program part oriented (1) to the system demonstration of the electronic brassboard subsystems, and (2) the achievement of VHSICs with submicron (nominally 0.5 to 0.8 geometries) by about 1985.

Phase III - Technology efforts which are generic in nature and which are supportive of Phase I and Phase II.

Impact of the DoD VHSIC Program On The Integrated Circuit Industry

Several questions have been raised pertaining to the impact that the DoD's VHSIC program will have on the integrated circuit industry. Some of the more thought-provoking are:

Will the VHSIC program further aggravate present manpower shortages in the IC industry ?

Could the VHSIC program greatly help a few companies and thereby skew the marketplace ?

Will a commercial market develop for advanced VHSICs ?

The DoD stimulated the growth of the IC industry in the 1960s by demonstrating the feasibility of fabricating ICs, and by providing a viable market. This was followed by a rapid expansion of technology through government reports, transfer of personnel among companies, and establishment of second source and licensing. In some cases, once one company announced or introduced a new process or product, the same result was repeated in other companies. The DoD feels the same process will be repeated to a considerable extent with VHSIC. The DoD hopes to prove the feasibility and provide demonstrations of VHSIC. Some of the program's goals themselves will help to insure that a DoD market will rapidly accrue. The near-term goal of the 1.3 micron design rule could coincide with commercial markets in 1982. This could also stimulate commercial production. ICs that are developed under the VHSIC program will be MIL-Spec qualified, allowing immediate DoD use.

The specific VHSIC team members & proposed technology offerings have not been officially disclosed as of this date. Table 5-4 lists the teaming member combinations mentioned in the press as most probable.

VHSIC Architecture

A structure by which VHSIC devices are interconnected, addressed and programmed to meet design objectives of application algorithms. This efinition includes interconnection or busing, instruction set, special functions, control, and addressing I/O schemes, all compatible with an operating system including executive and language programming.

Lithography

It is expected that Phase Ia chip technology will be satisfied with presently-available lithography equipment. Development of advanced lithography equipment for submicron fabrication (such as e-beam or X-ray equipment) can be included as part of Phase Ib in a vertically integrated effort. or can be included as part of Phase III in response to an RFP, or need not be included in either. This will be an option of the offeror. If bid as part of a vertically integrated effort, it will be clearly separated from other efforts. Simplified program goals are listed as a function of lithography feature sizes in Table 5-5.

JAN 38510 Class B Market

In the integrated circuit industry, the terms "hi-rel" and "JAN" are often used synonymously and, all too often, loosely. The MIL-M-38510 JAN integrated circuit program was established in 1968 by the Rome Air Development Command (RADC) of the United States Air Force. This program was lished to control the wafer processing,

assembly, electrical testing, overall package integrity and environmental testing of integrated circuit devices. The controlling Military Standard is MIL MIL-STD 883, established in 1968. On recent military programs the Department of Defense has mandated that MIL-M-38510 devices, when available, will be used by the prime and subcontractors in all military and aerospace contracts. A current coordination between the National Aeronautics and Space Administration (NASA), the Air Force Systems Command (SAMSO), and RADC has consolidated the generation of hi-rel processing specifications for the DoD and other governmental agencies. This will enable both NASA and SAMSO to make meaningful quantity buys that will be profitable for the semiconductor industry to manufacture. The "S" classification is one attempt with the vendors to replace the unworkable Class "A" specification. The Class B served available market (SAM) for digital products is broken out by vendor in Table 5-6.

PRELIMINARY CLASS S MARKET NUMBERS

Class S Jan Market (Space Programs)

The Class S requirements are designed to circumvent known problems. In general, each requirement matches up to a problem the DoD has had one or more times in the past. (These are not things that were invented without any real basis.) The effectiveness of the Class S requirements is predicated on the implementation of all of them. There aren't any magic requirements which can be implemented to the exclusion of the others. The DoD is depending upon the implementation of the entire specification and all of its requirements to achieve this high quality. Finally, the Class S requirements were derived from specifications which the DoD has successfully used in the past on prior space programs; they reflect screening & test methods which have proven effective for the DoD. The design and construction rules in the specifications are there to preclude known reliability problems. The established control techniques in the specification have been used by the DoD in the past. All of these requirements have received extensive coordination with both contractors and manufacturers. The total available market (TAM) for Class S products is estimated in Table 5-7.

SAMSO has summarized the Class S requirements by breaking them into nine major catagories:

1. Manufacturing baseline.
2. Design & construction requirements.
3. Product assurance program.
4. Certification of manufacturers.

5. Class S qualification requirements.

6. Wafer lot acceptance.

7. Class S Screening requirements.

8. Quality conformance testing.

9. Government Source Inspection (GSI).

The evolvement of Class S devices under MIL-M-38510D, and more significantly, the joining of DESC, NASA and SAMSO to effectively administer and invoke the Class S qualification & certification requirements, confirms the government's belief that working together on this issue is the way to go. Wide support exists at the command level for the program. In the past, DESC, NASA and SAMSO have been essentially operating independently to quality high reliability parts. DESC has administered qualification for Class B and C devices, and has authorized testing and evaluated test reports for the old Class A devices. NASA has conducted its own line-certification audits for the old Class A devices. SAMSO is administering its own quality program under MIL-M-00385-10B.

The method by which DESC, SAMSO & NASA will work together in the Class S qualification program will be reviewed by the Defense Electronics Supply Center , DESC-EQ, as the DoD focal point for the JAN Microcircuit program. DESC-EQ will also perform all administrative work on Class S devices.

The key point in Class S qualification is the provision for a joint team audit composed of individual members from each government activity that has an interest. This will result in several advantages:

a. Minimize company's time spent during audits.

b. Eliminate audit duplication and overlap.

c. Reduce overall government audit expense.

d. Improve uniformity of audits.

To effect this last advantage, the government plans to restrict the number of participants performing the audit to provice an efficient team. Only the people essential for the audit will be in attendance. This will ensure cost effectiveness and provide a uniform audit in minimum time.

NASA/SAMSO feel that, aside from the qualification program, other goals need to be accomplished. With the incorporation of Class S devices in MIL-M-38510D, the DoD should strive to establish Class S devices as preferred for logistics purposes. This would minimize the number of varieties of devices

that need to be stocked for support purposes. While the cost of Class S devices initially would be somewhat higher, an increase in usage may make it feasible to stock only the Class level devices for replacement purposes. In most cases the net result would be lower life cycle costs.

Selected Military/Aerospace Supplier Profiles

The following supplier profiles outline specific supplier activities, special interests & capabilities & U. S. sales in the military/aerospace market.

Texas Instruments (TI)

TI continues to support the Mil-M-3851 38510 JAN integrated circuit program, both Class B and Class S. TI has been a leader in the utilization of electron-beam mask-projection systems that will be a major factor in providing complex device geometries in the sub-micron (0.5 micron) feature size as required for the VHSIC program.

National Semiconductor

National Semiconductor continues to maintain its position as a major supplier to the military/aerospace market. National will continue to take advantage of its position as a major supplier of radiation-hardened CMOS and radiation-hardened linear integrated circuits. National has had a major investment to support the VHSIC program, and is presently one of the few suppliers presently in possession of both VLSI and rad-hard capabilities.

Fairchild Semiconductor

Fairchild has realigned its bipolar military operations and has established within that operation that bipolar LSI military hi-rel strategic business unit, with emphasis to be placed on bipolar memories and RAMs. Fairchild plans to participate in the VHSIC program.

Signetics

Signetics continues to be an effective supplier of military/aerospace high-reliability products and is a major participant in the *Class S space parts* 38510 program. Signetics intends to participate in the VHSIC program, teaming with Hughes Aircraft, utilizing Signetics' injection Schottky logic process. Signetics continues to secure qualifications to MIL-M-38510 for its linear analog bipolar devices and also continues to be a major supplier of bipolar PROMs to the military/aerospace marketplace.

Motorola

Motorola has established a bipolar high-reliability operations center in the Mesa, Arizona facility. Motorola continues to process MOS & CMOS military products at the Austin facility.

One of the key problems that Motorola exhibits is one of duplicated operations on a division-by-division level, as it has not yet established a centralized high-reliability profit- and-loss center. Motorola is reportedly teamed with. TRW and Univac on the VHSIC program.

Advanced Micro Devices

AMD has elected not to participate in the VHSIC program, primarily because this would create a dilution of corporate resources, especially manpower. AMD continues to support the JAN (MIL-M-38510). The AMD 2901 bipolar microprocessor continues to be a standard for military bit-slice computers.

Harris

Harris has been long known for its radiation-hardened capabilities, and Harris is involved in many programs of a classified nature which support the National Security Agency and SAMSO in the area of recommaissance and secured communications systems. Harris has made a major commitment to support both Class B and Class S of the MIL-M-38510 program.

Intersil

Intersil continues to support its Independent Hi-rel profit-and-loss center.

Intersil's strengths come in support of the precision analog linear integrated circuit market segment, as well as low-power CMOS as applied to military and aerospace systems. Intersil is reportedly teamed with GE on the VHSIC program.

RCA

RCA has continued to support the MIL-M-38510 Class B and Class S. RCA is known for providing good engineering support to its customers and to various DoD agencies. RCA's microprocessor, the CDP-1802, has been designed into several major systems. RCA also continues to supply rad-hard devices to selected military/aerospace programs.

Rockwell

Rockwell has been a major supplier of semicustom military devices to such agencies as SAMSO and NASA in the area of secured communication systems as well as reconnaissance and spy-in-the-sky satellite systems. Rockwell has bid Phase O of the VHSIC program and has made long-term major investments in silicon and gallium arsenide technologies. Rockwell has done an effective job in supporting and servicing the program management offices at various DoD agencies.

Captive Military/Aerospace IC In-House Facilities

Over the last decade, the military contractors have been unable to use

captive IC facilities effectively for production of ground-based computer equipment. For the next decade, there is growing realization that the integration level of military components will have to be raised significantly... to take advantage of the enhanced reliability and lower costs associated with VLSI. The VHSIC program is aimed at this objective, but contractors will continue to use a number of approaches, including standard design, custom design with outside manufacture, and in-house design and manufacture. The sophistication level of IC processing is expected to be very high, encouraging in-house design coupled with outside processing by a qualified volume producer. The status of various process technologies at selected military/aerospace system houses is reviewed in Table 5-8.

PRIME VHSIC PROGRAM GOALS PROVIDE THE DoD IC WITH:

- REAL-TIME, HIGH SPEED, MILITARY SIGNAL PROCESSING CAPABILITIES
- MILITARY SYSTEM ARCHITECTURE AND IC DESIGN. THIS REDUCES COST/TIME OF IC ACQUISITION
- MILITARY IC CHIP DESIGNS TO INCLUDE ON-CHIP TESTING AND FAULT TOLERANT CONCEPTS
- IC TECHNOLOGY SUITABLE FOR MILITARY QUALIFICATION

THE VHSIC PROGRAM IS A CATALYTIC EFFORT THAT WILL BENEFIT INDUSTRY BY

- INCREASING MILITARY SALES
- STIMULATING INDUSTRIAL INNOVATION
- ADVANCING THE GENERAL IC TECHNOLOGY THROUGH PRODUCT AND EQUIPMENT ADVANCEMENTS

SUCCESSFUL COMPLETION OF THE VHSIC PROGRAM WILL RESULT IN:

- DoD BEING ABLE TO EXTEND ITS TECHNOLOGICAL LEADERSHIP IN MILITARY ELECTRONICS
- REDUCE LIFE CYCLE COSTS
- INSERTION OF NEW VHSIC TECHNOLOGY INTO MILITARY SYSTEMS

REASON: THE PROGRAM IS SYSTEM DRIVEN
THE VHSIC DEVICES ARE
AVAILABLE
AFFORDABLE
EASY-TO-USE

PHASE 0 CONTRACT PROGRAM ELEMENTS

- MILITARY ELECTRONICS SYSTEMS ARCHITECTURE
  CAD SYSTEMS AND METHODS
  TEST TECHNOLOGY AND TEST SYSTEMS
- ADVANCE IC TECHNOLOGY DEVELOPMENT PROCESSES
  PROCESS EQUIPMENT

PHASE 0 BIDDERS WHO WERE NOT AWARDED PHASE 0 CONTRACTS

SYSTEM MANUFACTURERS	U.S. SEMICONDUCTOR MANUFACTURERS	TECHNOLOGY
HARRIS	HARRIS SEMICONDUCTOR	CMOS, SOS/CMOS
BOEING/UNIV. OF UTAH	GENERAL INSTRUMENT	NMOS, BIPOLAR
BELL LABS	WESTERN ELECTRIC	CMOS, N-CHANNEL MOS

JAN 38510 SAMS DIGITAL IC MARKET 1978 to 1981 CLASS B

$ = MILLIONS

MFR.	TTL 1978	1979	1980	1981	TOTAL	S & LS 1978	1979	1980	1981	TOTAL	BIPOLAR MEMORIES 1978	1979	1980	1981	TOTAL	CMOS 1978	1979	1980	1981	TOTAL
TI	5.0	6.66	7.407	8.341	27.408	5.0	6.65	8.407	8.341	28.408	—	—	—	—	—	—	—	—	—	—
FAIRCHILD	.5	.505	.640	.733	2.447	.5	.505	.640	.733	2.447	—	—	—	—	—	—	—	—	—	—
MOTOROLA	.5	.505	.640	.733	2.447	1.0	2.13	2.200	2.467	[illegible]	—	—	—	—	—	—	—	—	—	—
NATIONAL	1.5	1.095	2.949	2.202	8.346	2.8	3.26	3.500	3.030	12.795	—	—	—	—	—	1.0	1.12	1.200	1.467	4.888
SIGNETICS	3.0	3.20	3.500	2.936	11.795	3.0	4.30	.800	6.404	15.002	.5	.904	1.030	1.174	3.917	—	—	—	—	—
AMD	.5	.505	.640	.733	2.447	.5	.505	.640	.733	2.447	—	—	—	—	—	—	—	—	—	—
RCA	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	.5	.505	.640	.733	2.447
MMI	—	—	—	—	—	—	—	—	—	—	.5	.904	1.030	1.174	3.917	—	—	—	—	—
TOTALS	10.6	13.3	16.802	15.676	54.870	12.0	17.600	21.501	24.614	75.785	1.0	1.808	2.078	2.348	7.634	1.5	1.808	1.840	2.80	7.342

DOES NOT INCLUDE MOS

NOTE FLAT PACKS WILL MOVE FROM THE CURRENT REQUIREMENTS OF 30% TO 85% OF JAN 38510 SHIPMENTS FOR YEARS 1979 1980, 1981

NOTE THE INCREASES IN THE U.S. MIL M 38510 (JAN) SALES ARE AS FOLLOWS

1. B-52 RETROFIT
   F-15 RETROFIT
   F-16 AVIONICS
   F-18 AVIONICS
   CRUISE MISSLE
2. ALL DoD PROGRAMS WILL REQUIRE MIL M 38510 ICs
3. NEW DEVELOPMENT PROGRAMS WILL REQUIRE MIL M 38510 ICs

TEAM MEMBERS WINNING PHASE 0 CONTRACTS

CONTRACTS AWARDED MARCH 7, 1980
STARTED APRIL 12, 1980—COMPLETED JANUARY, 1981

SYSTEM MANUFACTURERS	U.S. SEMICONDUCTOR MANUFACTURERS	TECHNOLOGY	DoD AGENCY ASSIGNMENT
TI	TI	N-CHANNEL MOS I^2L	AIRFORCE (WPAF DAYTON)
RAYTHEON	FAIRCHILD	ECL CCD	AIRFORCE (WPAF DAYTON)
HONEYWELL/3M	—	BIPOLAR	AIRFORCE (WPAF DAYTON)
IBM	—	N-CHANNEL MOS BIPOLAR	NAVY (WRL WASHINGTON)
TRW/UNIVAC/GCA	MOTOROLA	BIPOLAR TRIPLE DIFFUSED CMOS	NAVY (WRL WASHINGTON)
WESTINGHOUSE	NATIONAL SEMICONDUCTOR	CMOS, BIPOLAR	NAVY (WRL WASHINGTON)
HUGHES	SIGNETICS	I^2L, CMOS	ARMY (FT. MONMOUTH, N.J.)
ROCKWELL/SANDERS	ROCKWELL	CMOS, CMOS/SOS N-CHANNEL MOS	ARMY (FT. MONMOUTH, N.J.)

NOTE: AIRFORCE VHSIC PROGRAM DIRECTOR — MR. JOHN BLASINGAME, AVIONICS LAB ELECTRONIC TECHNOLOGY DIV.
NAVY VHSIC PROGRAM DIRECTOR — MR. NATHAN BUTLER, NAVAL ELECTRONICS COMMAND
ARMY VHSIC PROGRAM DIRECTOR — DR. CLARE THORNTON, ELECTRONICS LAB

VHSIC DESIGN RULES

NEAR-TERM, 1.3 MICRON DESIGN RULES

1. GREATER THAN 30 MHz CLOCK RATE
2. STATIC RAM CHIPS (64K BIT MINIMUM)
3. ADDITIONAL CHIP TYPES SUCH AS PLAs, CGAs, A/D CONVERTERS, MULTIPLIERS, ETC. (FINAL SET COMPATIBLE WITH IDENTIFIED SYSTEM DEMONSTRATIONS)
4. FIGURE OF MERIT GREATER THAN 10^{11}/CM² NUMBER OF EQUIVALENT GATES TIMES CLOCK RATE
5. CHIPS CAPABLE OF MIL SPEC PERFORMANCE
6. CHIPS TOLERANT OF MAN-SURVIVABLE RADIATION
7. INCLUSION OF APPROPRIATE FAULT-TOLERANCE AND BUILT-IN TEST DESIGN
8. DEDICATED LINE PRODUCTION CAPABILITY
9. CHIP SETS FOR IDENTIFIED SYSTEM DEMONSTRATIONS
10. APPROPRIATE TEST CHIPS TO DEMONSTRATE MULTI-LEVEL METALIZATION AND OTHER FEATURES NECESSARY FOR EVENTUAL SUBMICRON CHIP DEVELOPMENT.

LONG-TERM, SUBMICRON (0.5-0.8 MICRON) DESIGN RULES

1. GREATER THAN 100 MHz CLOCK RATE
2. STATIC RAM CHIPS (¼ MBIT MINIMUM)
3. FIGURE OF MERIT OF ABOUT 10^{13}/CM² (NUMBER OF EQUIVALENT GATES TIMES CLOCK RATE)
4. CHIPS CAPABLE OF MIL SPEC PERFORMANCE
5. FAILURE RATE EQUAL OR LESS THAN 0.1% PER 1000 HOURS AT 125°C AMBIENT.
6. FAULT-TOLERANT/BUILT-IN TEST ARCHITECTURES
7. DEDICATED LINE PRODUCTION CAPABILITY
8. CHIP SETS FOR IDENTIFIED SYSTEM DEMONSTRATIONS

U.S. SEMICONDUCTOR MANUFACTURERS SUPPORT OF DoD/AEROSPACE PROGRAMS AND TECHNOLOGY

U.S. SEMICONDUCTOR MANUFACTURER	PRODUCT/TECHNOLOGY: DoD AGENCY SUPPORT	JAN 38510 (B)	JAN 38510 (S)	EB SUB MICRON	CUSTOM LSI VLSI	CO RADS	HMOS	SOS	I^2L	GaAs	OVERALL RATING
TI +	S	S	A	S	W	S	W	W	S	S	S
MOTOROLA +	A	A	W	A	A	W	S	W	A	N/A	A
FAIRCHILD +	A	A	W	S	W	S	W	W	S	N/A	A
NATIONAL* +	S	S	S	S	W	A	A	W	A	N/A	S
SIGNETICS +	S	S	S	S	A	S	W	W	S	N/A	S
HARRIS*	S	S	S	A	S	S	A	W	W	N/A	S
PMI	S	S	A	N/A	N/A	S	N/A	N/A	W	N/A	A
AMD	A	S	A	W	W	A	A	W	W	N/A	A
AMI +	S	A	W	N/A	S	S	S	W	W	N/A	A
INTERSIL +	W	A	W	W	A	A	W	W	W	N/A	W
INTEL	W	W	W	A	W	S	S	A	W	N/A	W
SILICONIX	A	A	A	W	S	S	W	W	W	N/A	A
RCA*	A	A	S	A	A	S	W	S	W	S	A
MMI	A	A	A	W	W	A	N/A	W	W	N/A	A
ROCKWELL* +	S	S	W	S	S	S	A	S	W	S	S

KEY: S = STRONG; A = ACCEPTABLE; W = WEAK/NON EXISTENT; N/A = NON APPLICABLE
+ = SUPPORT OF THE VHSIC PROGRAM
* = RAD HARD PROGRAM

IN-HOUSE TECHNOLOGIES LOCATED AT MILITARY/AEROSPACE SYSTEM HOUSES

	RAD HARD	PMOS	NMOS	CMOS	SOS	BIP DIG	BIP LINEAR	I^2L	GaAs
GENERAL ELECTRIC	D	*	D	D	*	D	*	*	D
GTE/SYLVANIA	—	**	—	**	—	**	**	—	—
HARRIS	**	**	**	**	—	**	**	—	—
HONEYWELL	D	**	**	**	—	*	*	*	—
HUGHES	D	**	D	**	*	*	D	D	D
IBM	—	—	**	D	D	**	**	D	D
LOCKHEED	*	**	—	D	D	**	**	—	D
MOTOROLA	—	**	**	**	—	**	**	**	D
McDONNELL-DOUGLAS	—	D	D	—	—	—	—	—	D
RAYTHEON	—	—	—	—	—	**	**	—	D
RCA	D	—	*	**	**	**	**	**	D
SPERRY	—	—	D	D	D	**	D	—	D
ROCKWELL	D	**	**	—	D	—	—	—	D
TEXAS INSTRUMENTS	—	**	**	**	D	**	**	**	D
TRW	—	—	—	D	—	**	**	D	D
WESTINGHOUSE	—	—	—	D	D	—	—	—	D

D = Development
* = Pilot Production
** = Production

MILITARY/AEROSPACE SUPPLIERS

MFR	MOS 1977	MOS 1978	MOS 1979	MOS 1980	LINEAR 1977	LINEAR 1978	LINEAR 1979	LINEAR 1980	DIGITAL 1977	DIGITAL 1978	DIGITAL 1979	DIGITAL 1980	HYBRID 1977	HYBRID 1978	HYBRID 1979	HYBRID 1980	TOTAL 1977	TOTAL 1978	TOTAL 1979	TOTAL 1980
TI	3.0	3.5	4.0	4.5	8.0	11.0	13.0	14.7	55.0	45.0	55.0	62.1	5.0	4.0	5.0	5.7	71.0	63.5	77.0	87.0
NATIONAL	2.0	4.0	5.0	6.7	13.5	14.0	16.0	17.0	10.0	13.0	14.5	16.4	5.0	8.0	8.0	10.1	30.5	39.0	43.5	50.2
FAIRCHILD	3.0	3.5	4.3	4.8	6.0	8.0	10.8	12.2	13.0	10.0	12.2	13.8	3.0	2.0	3.2	3.8	27.0	24.5	30.5	34.6
SIGNETICS	2.5	3.0	6.6	4.5	4.5	6.0	6.0	6.7	18.0	26.0	32.0	36.2	—	—	—	—	25.0	33.0	41.0	40.4
MOTOROLA	8.0	10.0	11.0	13.4	6.5	4.0	6.0	6.7	9.0	18.0	19.0	21.4	—	—	—	—	23.5	32.0	36.0	38.5
AMD	4.0	7.0	8.0	9.1	6.5	10.0	11.3	12.7	8.0	13.0	14.5	18.4	—	—	—	—	18.5	30.0	33.8	40.2
MMI	—	—	—	—	—	—	—	—	10.0	13.0	19.6	22.1	—	—	—	—	10.0	13.0	19.6	22.1
HARRIS	5.0	9.0	11.0	12.4	8.0	11.0	13.5	16.2	3.0	4.0	8.0	9.1	—	—	—	—	16.0	24.0	32.5	37.7
INTERSIL	—	2.0	4.0	4.5	10.0	12.0	14.0	15.8	—	—	—	—	4.0	6.0	7.5	8.5	14.0	18.0	25.5	28.8
RCA	9.0	12.0	14.0	15.8	2.5	3.5	5.5	6.2	—	—	—	—	—	—	—	—	11.5	15.5	19.5	22.0
INTEL	10.0	8.5	12.5	14.1	—	—	—	—	—	—	—	—	—	—	—	—	10.0	8.5	12.5	14.1
TOTAL	46.5	62.5	77.6	87.8	76.5	90.5	93.1	105.2	135.0	148.5	174.8	197.6	17.0	18.0	24.7	27.8	275.0	321.5	370.4	418.6

A SELECTED REVIEW OF CANDIDATE SYSTEMS FOR PHASE 0 VHSIC PROGRAM DEFINITION PHASE

DoD AGENCY	PROGRAM/SYSTEM
U.S. ARMY	TACTICAL INTEGRATED EW WEAPONS SIGNAL PROCESSOR (PARAMETER MEASUREMENT UNIT, MODULAR ADAPTIVE SIGNAL SORTER, ETC.)
	FIRE AND FORGET MISSILE ELECTRONICS (RF ACTIVE/PASSIVE AND/OR EO PROCESSOR)
	ADVANCED TACTICAL DATA/VOICE DISTRIBUTION AND NAVIGATION PROCESSOR (ADDS PLUS)
U.S. ARMY	BACK-PACK COMMUNICATIONS
U.S. NAVY	MICRO-VECTOR PROCESSOR (MVP) F-14 CILOP MULTISENSOR PROCESSOR
(TENTATIVE SYSTEMS)	E-2C AEW RADAR FIGHTER/ATTACK INTEGRATED RADAR (FAIR) TACTICAL INFORMATION EXCHANGE SYSTEM (TIES)
U.S. NAVY	ARRAY VECTOR PROCESSOR (ACOUSTIC) AYK-14 UYK-20 RADAR SIGNAL PROCESSOR IMAGE PROCESSOR (SAR) BEANFORMER (SOSUS) NATO ID SYSTEM ANTIJAM COMMUNICATIONS MODEM 32 BIT GENERAL PURPOSE PROCESSOR
U.S. AIR FORCE	PROGRAMMABLE SIGNAL PROCESSORS FOR ADVANCED AIRBORNE ALL-WEATHER TACTICAL STRIKE COMMUNICATIONS SIGNAL PROCESSOR FOR JTIDS ATTACK RADAR

SUPPLIER OVERVIEW OF SPACE PARTS

MICROELECTRONIC PROCUREMENT

Dick Lambert
SIGNETICS CORPORATION
Chairman, JEDEC JC-13.2

Ladies and gentlemen; when Jim Wiesner called to ask that someone from my Government Liaison Committee speak to this group on space parts procurement issues, I knew this someone would be placed in a difficult, no win position. Our JEDEC efforts have been directed toward the solution of technical issues and, unfortunately, there is no legal means to coordinate supplier positions on subjects that relate to procurements. This single area has been most overlooked in the recent developmental years, and is a very significant contributor to today's problems. Having picked the short straw in my committee, I hope today to present the suppliers view of spaceparts procurement without, hopefully, showing too much of my Signetics' bias, or otherwise being placed in a compromising position with my supplier counterparts. I cannot, unfortunately, speak as a single representative for my industry on these issues--and with that disclaimer out of the way, I'll proceed.

In support of the stated theme of this workshop, I've segregated my comments to the five bullits on my first foil. I'll be commenting on the market, small volume buys, coordinated procurement, the factors that motivate or otherwise demotivate suppliers, and fianlly, I'll wrap up with a few suggestions on how to go forward with this program. If you'll hold your comments and questions, there'll be time for these at the end of the presentation.

Our view of the spaceparts market is one of the mixed emotion. The industry data available on the market indicates a larger share of the overall DOD market going to space over the next 10 years. Unfortunately, we lack specifics. The major programs--the attention getters--have not settled into a regular, predictable procurement cycle. Other smaller programs pop up sporadically, without the commitment for follow-on requirements, specifically, NASA requirements have been masked by the inordinate Shuttle proccupation in recent years--and the bulk of that programs needs are in Class B, B+ or Quasi-A.

Technical needs are fragmented. We continue to support the needs of the older programs such as 85MO, MIL-M-0038510, and P-95. The technical content of these requirements--in comparison to today's Class S or even with each other--do nothing to promote standardization. The myriad of other pro-

gram oriented, SCD based requirements, cause absolute chaos in the supplier community.

Major programs dominate and in themselves create residuals--these are over-run inventories. This would normally be good for all if only the requirements were identical. Most often they are not, and the user is placed in a position of risk vs. availability.

The next graph illustrates our view of the spaceparts electronic growth in the next decade, as compared with the overall DOD electronic growth. I apologize for the normalization, but the numbers are not only controversial, but include far more than simple component contributions. Our assumption, of course, is that a form of standardization has taken place in this initial phase so that this growth is supplemented by the combining of similar requirements. The next foil is an optimistic view of what we'd like to see in the market's transition to JAN Class S procurement. Let me restate that--this illustrates what we expect to see in the market over the next few years. We would be very disappointed to see anything less ambitious. JAN Class S standardization is mandatory if the system of space component procurement is to succeed.

You can see that we expect to reach 50% procurement standardization by 1982. I believe the suppliers will provide the primary motivation to meet this objective. Non-standard procurement to custom SCD requirements will become extremely difficult, if not impossible. In addition, an increasing segment of the diminishing non-JAN/SCD procurement will consist of part types with no existing slash sheets, but will be processed to an identical 38510 flow as JAN Class S. Custom flows with all the associated bells and whistles will become a rarity. Spec negotiation will become absolutely non existant.

I've listed the problems of small volume procurement on the next foil, and I expect a lot of head nodding on this one. The problems are somewhat obvious, and somewhat analgous to the situation with Class B microcircuits in the 1972-1975 time frame. It is extremely difficult to get the ball rolling, but once it is, it's all down hill.

At the moment JAN Class S microcircuits are simply not available. A very few users have had the inclination to buy straight JAN Class S and fewer suppliers have committed to an inventory plan of any kind. Those bloodied suppliers who have survived the certification process realize now that the demand on resources to support the program is significant. Most are unwilling to go further by initiation qualification testing without user procurement.

Lack of JAN availability promotes and somehow endorses non-standard procurement. SCD requirements usually

lack the MIL Spec due to the volatile nature of the evolving requirements. Out of date SCD's eventually turn into non-standard requirements thereby feeding fuel to the problem.

Initial procurements are small, high risk, and are fixed priced contracts. Suppliers are producing first article part types and face start up problems associated with the most difficult class of product available. Little or no inventories exist and, as a result, lead times are unbearably long and very uncertain.

Coordinated procurement at this point doesn't do much for the supplier. The obvious benefits associated with larger order quantities are countered by a few technical and administrative difficulties. Specifically, non-standard requirements in the electrical characteristics or the process flows detract from the coordination benefits. Procurement delays result from the basic communication problems existing between the prime and sub, the problems involved in device selection, and the difficulties associated with pricing non-standard requirements. True coordination, of course, would be nice--but a dedication must first be made to uncompromised standardization. When all parties agree on straight JAN Class S, coordinated procurement issues will disappear.

Now I'd like to go into the motivation issues--these can best be illustrated by going through a bit of recent history. Back in the mid 70's many manufacturer's were participating in the NASA, Class A certification program. True Class A processed parts were nonexistant--every program had its unique set of characteristics and flows--JAN standardization simply wasn't a serious issue. Yet manufacturers seemed blind to these shortcomings, and eagerly pursued more and more certifications The issue was that of being in a ready position should an opportunity arise. It was nice, also, to paper the lobby with the certifications--nice copy to show off to your customers.

Just as the ROI reality was dawning in 1976, SAMSO and Aerospace launched their successful effort to coordinate suppliers and users on "The New" Class S set of requirements. The lure of potential standardization revitalized the spirit of the suppliers. In 1977, the first set of Class S MIL-Specs were on the streets and, in December, SAMSO/ Aerospace had a kick-off meeting to motivate all of the potential suppliers. GPS and IUS loomed on the horizon as a great carrot in the sky. In 1978, the benefits of standardization seemed to temper the risk of lost investment-also, the initial certifications were then in progress. Efforts to fine tune the specs were continuing with excellent cooperation between NASA, SAMSO, Aerospace and JEDEC. Despite a lengthy certification learning curve, the first certifications were issued in early 1979.

Manufacturers waited breathlessly for the onslaught of orders after the first Class S parts were listed on the QPL.

1980 holds the hope for the final conversion of the major programs to JAN Class S. Every indicator points to a successful climax to this long, painfull process. This is gratifying.

Unfortunately, there remains a few demotivators which influence today's procurement situation. Agency interactive delays have caused valuable time lost in the certification/qualification process, and this causes delays in the introduction of legitimate QPL part types. Granted, improvement has been dramatic since the first struggling days, but, to an impatient supplier, this factor represents a disappointment.

Options, whether contract imposed or allowable in MIL-Spec, demotivate a supplier from investing in inventories that may turn out non-saleable because of the existance, or lack of, a given option. This type of procurement approach promotes non-standardization simply becuase of the "personalization" of the resultant lots. Residuals from these lots are construed by other users as S +, S-, or simply unusable because of the simple uncertainty of the matter. A single non-standard option breeds curiousity about possible other non-standard slip-in's such that hours are invested by both user and supplier in cleansing the lots.

The technical MIL-Spec requirements are to say the least volatile. I might add that predominantly the suppliers have been pressing for the majority of these changes based on purely textbook reviews. The demotivating factor, oddly enough, comes from the effect felt in having the desired changes made to MIL-Spec, only to find that residuals suddenly become non-standard. Since the entire Class S Spec system is largely untested, one could expect a host of subtle problems to surface during the first few production runs.

We believe the largest demotivator is in the attitude of the space community users. We sense a user defensiveness which causes large expenditures of effort to avoid procurement of JAN Class S. This defensiveness is on the rationale experienced by the suppliers during the earlier days of Class B, as I mentioned earlier. Cost-lead time-availability- and the lack of second sources. If you are looking for a reason not to buy microcircuits--JAN Class S--go ahead and pick one. Perhaps more viable a cause, users cling to CSI-Customer Source Inspection-to validate the screening of the devices throughout the process. This has been ruled to be a "personalized" requirement and that government source shall suffice. The large user resistance is a significant negative factor to the supplier. A less significant factor is the requirement of the classic space user for baseline control. Admittedly, it is

difficult to abandon, to another party, responsibility for the control of the products.

Last, but certainly not least, our patience wanes as the ROI stays just beyond our grasp, and Class B demands on our resources and capacity continue to grow exponentially. Revenue, or lack of it, has a strangely dramatic effect on supplier motivation.

What, then, is at least one suppliers recommendations to press forward with the momentum of the past?

Re-examine the QPL rules. If the lack of a QPL source causes the user to write a non-standard SCD and procure from a non-certified supplier, why not instead allow a certified supplier to supply JAN Class S--and demonstrate its' ability to qualify the part prior to initial deliveries? The user assumes risk in both situations, but surely the risk is less in the latter case--and, it would promote the QPL in the process.

Place a moritorium on all new requirements. Why not allow a little time to shake out the system with a few orders before making more non-standard residuals?

Resolve the Class S options. Resolve yourselves to not being able to get more than one version. Sit down and work out a compromise acceptable to all parties.

Commit to JAN Class S. I mean stand up and make an uncompromised committment to this program-and it will work. There can be no conscious thought of alternatives unless it is absolutely necessary.

Forget the bells and whistles. Accept the fact that Class S is an order of magnatude more reliable than Class B, and that your little whiz-bang requirement will exert a small influence on that factor, if at all.

We feel quite strongly on these as being somewhat essential to the health of the system. One of the immerging strategies, which I believe to serve to promote the procurement issues, is that of contractor triggered stocking. A simple system--the first user triggers the system through his initial buy, and a planned stocking program is augmented in both die and finished forms. On subsequent buys, these inventory levels are examined and adjusted according to established run rates. Small volume needs are served through a planned approach to to residuals. Over-builds allow lot test charges to be amortized into larger quantities of the pieceparts such that these charges are less painfull, and *such that the first buyer isn't need*lessly punished by absorbing all the test charges. We think it's a good system--one ready to be tested.

Lastly, something should be done to provide better forecasting of program

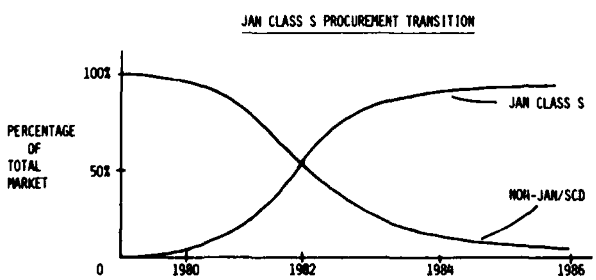
material needs. Lead time can hardly improve if forecasts continue to be uncertain in both quantities and time.

My industry is to a large degree enthusiastic about the JAN Class S program. We're willing to work with you to satisfy your fears, concerns, and heart-burn. Let's make this effort rewarding to all!

Thank You.

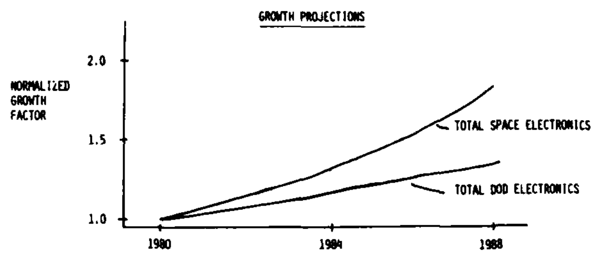
SUPPLIER OVERVIEW OF SPACEPART MICROELECTRONICS PROCUREMENT

- SPACE MICROELECTRONIC MARKET
- SMALL VOLUME PROCUREMENT
- COORDINATED PROCUREMENT
- SUPPLIER MOTIVATION
- RECOMMENDATIONS



SPACE MICROELECTRONIC MARKET

- DOD PROCUREMENT PROJECTED GROWTH
  - -TOTAL ELECTRONICS: 5% ANNUALLY
  - -SPACE ELECTRONICS: 13% ANNUALLY
- NASA NEEDS UNCERTAIN
- TECHNICAL REQUIREMENTS FRAGMENTED
- MAJOR PROGRAMS DOMINATION
- RESIDUALS



SMALL VOLUME PROCUREMENT PROBLEMS

- RESOURCE DEMANDING
- NON-STANDARD REQUIREMENTS
- HIGH RISK/FIXED PRICE CONTRACTS
- SMALL INVENTORIES
- LONG LEAD TIMES

RECOMMENDATIONS

- RE-EXAMINE QPL GUIDELINES
- REQUIREMENTS MORITORIUM
- NO CLASS S OPTIONS
- CONTRACTOR UNCOMPROMISED COMMITMENT TO JAN
- NO SCD BELLS AND WHISTLES - STANDARD FLOWS
- STRATEGIES
  - CONTRACTOR TRIGGER
  - WAFER STOCKING
  - PLANNED RESIDUALS/OVERBUILDS
  - AMORTIZED LOT CHARGES
- BETTER CONTRACTOR MATERIAL FORECASTS

SUPPLIER MOTIVATION

1976
- SPWG/SUPPLIER INTERCHANGE

1977
- CLASS S TECHNICAL REQUIREMENTS
- CLASS S KICK-OFF MEETING

1978
- PROGRAM VISIBILITY
- REDUCTION OF RISK/INVESTMENT
- INITIAL EFFORTS ON CERTIFICATION

1979
- CLOSURE ON CERTIFICATIONS
- QPL ACTIVITY

1980
- CONVERSION OF MAJOR PROGRAMS TO CLASS S
- FIRST JAN ORDERS

SUPPLIER DEMOTIVATION

- AGENCY INTERACTIVE DELAYS
- OPTIONS/NON-STANDARDIZATION
- TECHNICAL REQUIREMENTS EVOLUTION
- QPL DIFFICULTIES
- CONTRACTOR RELUCTANCE
  - COST
  - LEAD TIMES/AVAILABILITY
  - MULTIPLE SOURCE
  - CUSTOMER SOURCE INSPECTION
  - BASELINE CONTROL
- LITTLE ROI/PATIENCE
- LIMITED RESOURCES/CAPACITY

COORDINATED PROCUREMENT PROBLEMS

- NON-STANDARD REQUIREMENTS
- PROCUREMENT DELAYS
- FINANCIAL RESPONSIBILITY

SMALL VOLUME PROCUREMENT

Dale M. Cole

General Electric Company
Aircraft Equipment Division, Utica, NY

A major challenge facing the system manufacturers of space-oriented equipment is assuring that the program's schedules, cost, and quality goals are obtained on the ever-increasing small volume lots of components. This problem is amplified by the fact that the military part procurement over the years has become less and less of the total market place. One has only to look at the history of military procurement of semiconductors over the last decade and into the mid-eighties to realize that no longer is the military industry talking from strength to the semiconductor industry. Figure 1 shows that this trend is definitely downward and it is predicted to continue to go down to as low as 3 percent in the 1985 time frame. Of course, within the military 3 percent, the space industry procurement is estimated to be less than 0.3 percent of the total.

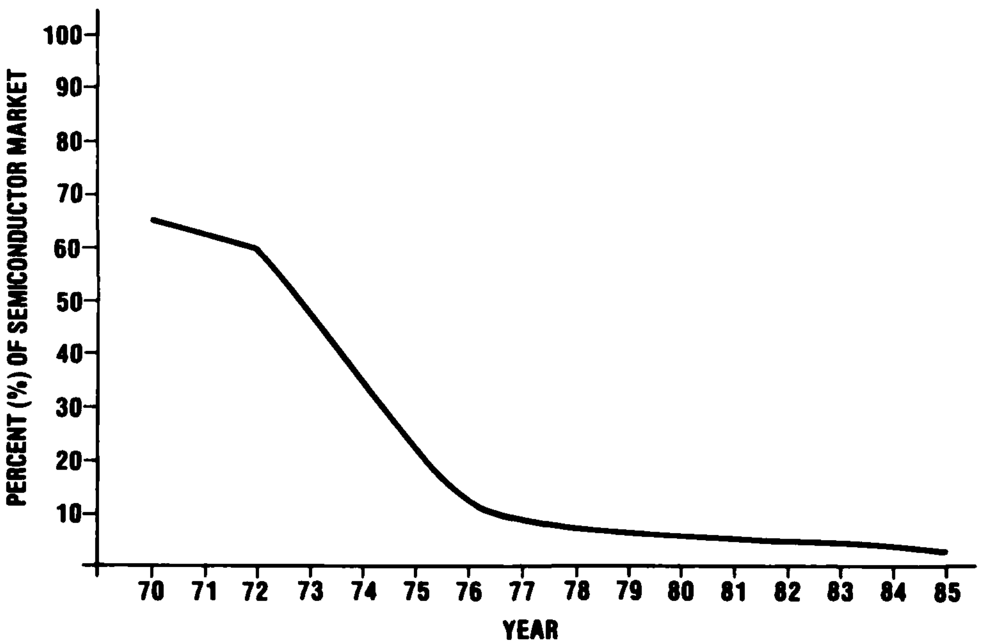


Figure 1. Military/Aerospace Market Trend - U.S. Semiconductor Industry

The effect of this market share on a given device type was emphasized in a recent microprocessor experience study performed by GE Aerospace Electronic Systems Department (GE/AESD) for NASA/MSFC (Contract NAS8-33142). Evidence of one of the major causes (automotive industry) of the erosion was clearly indicated in this study as Figure 2 shows the impact that the automotive industry is having on the 1802 microprocessor market in the 1980-81 time frame. Prior to 1979, the only use in the automotive industry was small prototype quantities to prove the feasibility of using the 1800 family in an electronic spark control system. This device proved to be an excellent choice in this environment due to its noise immunity capability and lower power consumption. Therefore, pilot runs (~100,000) of this system were manufactured in the 1979 models and full production (~500,000) will take place on the 1980 models.

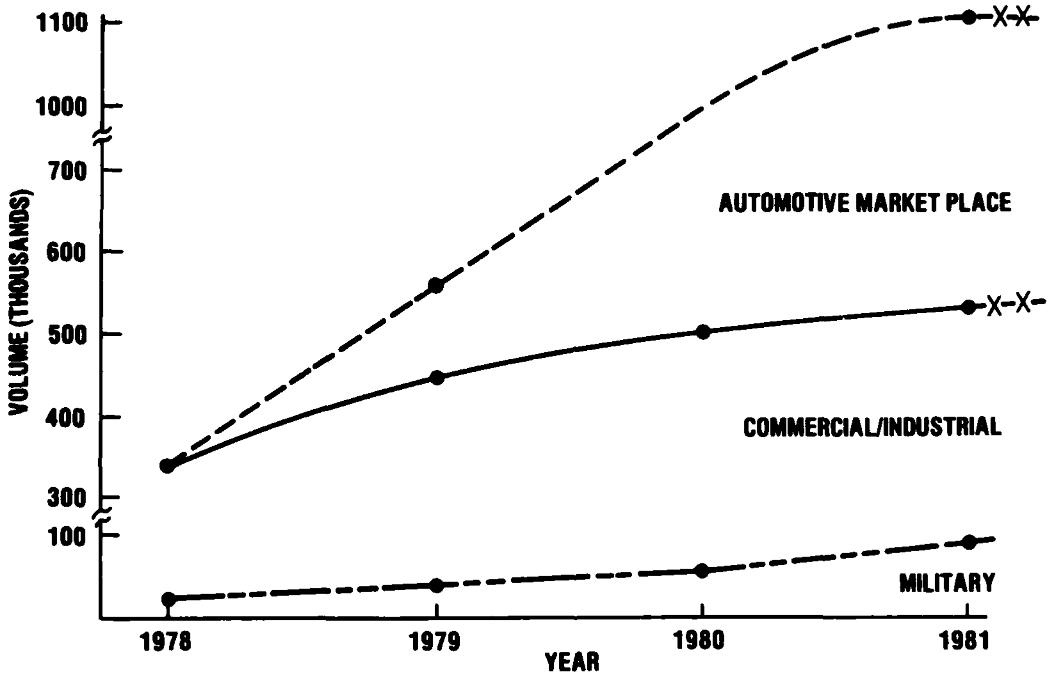


Figure 2. 1802 Microprocessor Volume Market Forecast

Listed below are some of the major causes of small lot procurement:

- Government funding policy and schedule requirements
- Use of state-of-the-art devices
- Lack of standardization
- Special requirements.

Government Funding Policy and Schedule Requirements

As all of us know, the government overall funding policy is at best an on and off again thing, depending on Congress's mood, the President's and DoD's requests. On top of this, we are expected to deliver at the maximum hundred of systems spaced over a multiple year procurement. All of this makes it next to impossible for the aerospace manufacturers to forecast their component requirements for more than one year with any validity. However, it is surprising how accurately (±5%) the consumer/industrial complex can predict their usage of millions of parts year after year.

Use of State-of-the-Art Devices

As the density and complexity of microcircuits continues to increase and more and more of the system function is designed onto a chip, the quantity procurement of any given device becomes significantly less. Figure 3 emphasizes this for a minicomputer. Where previously in SSI and MSI complexity it took 16 devices of five different types, now one LSI device is the complete function. Therefore, for a normal military fifty to a hundred system buy, the requirements would be 50 to 100 LSI devices versus 800 to 1600 SSI and MSI devices, dictating a small volume procurement.

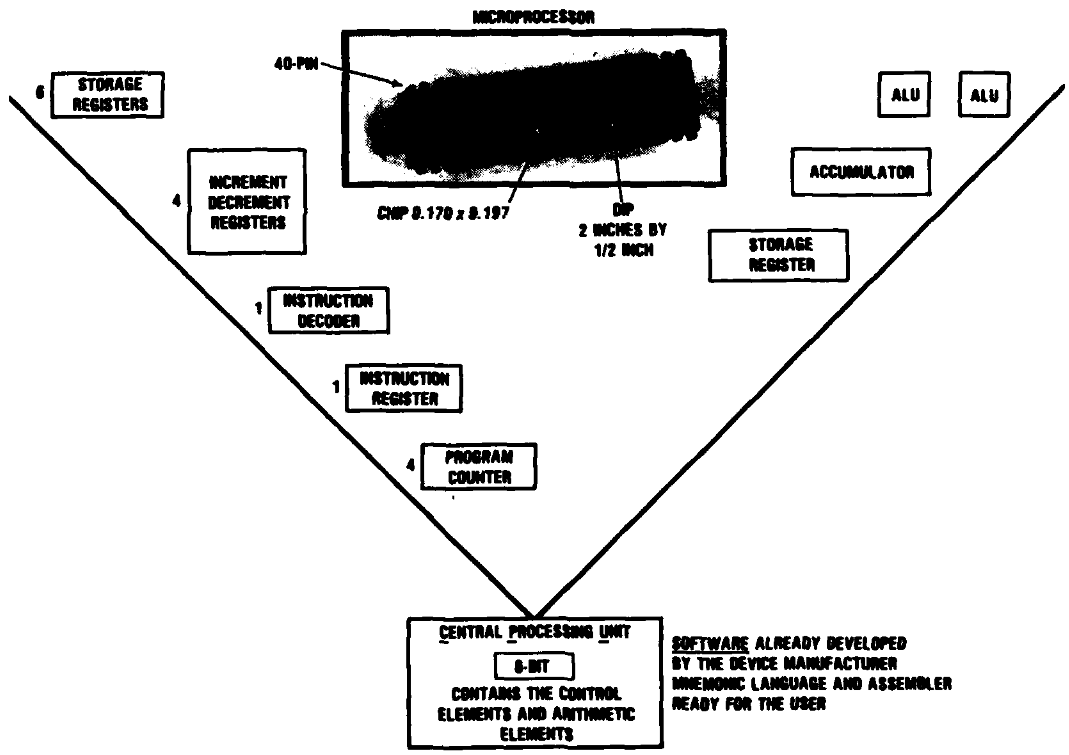


Figure 3. Use of State-of-the-Art Devices

As complexity increases, this trend will continue, causing many of the small volume procurements to be placed on the state-of-the-art devices (e.g., microprocessors, FPLAs, etc.) that are just leaving the learning curve. In addition, the aerospace community timing of production procurement on state-of-the-art devices usually coincides with the peak demand of the consumer/industrial community. An excellent example of this is the severe shortage of the 16K dynamic RAM (4116) that the consumer/industrial community is experiencing due to the computer industry needs; at the same time, the military complex is finding it being designed into almost all new memory designs. Figure 4 emphasizes graphically this problem.

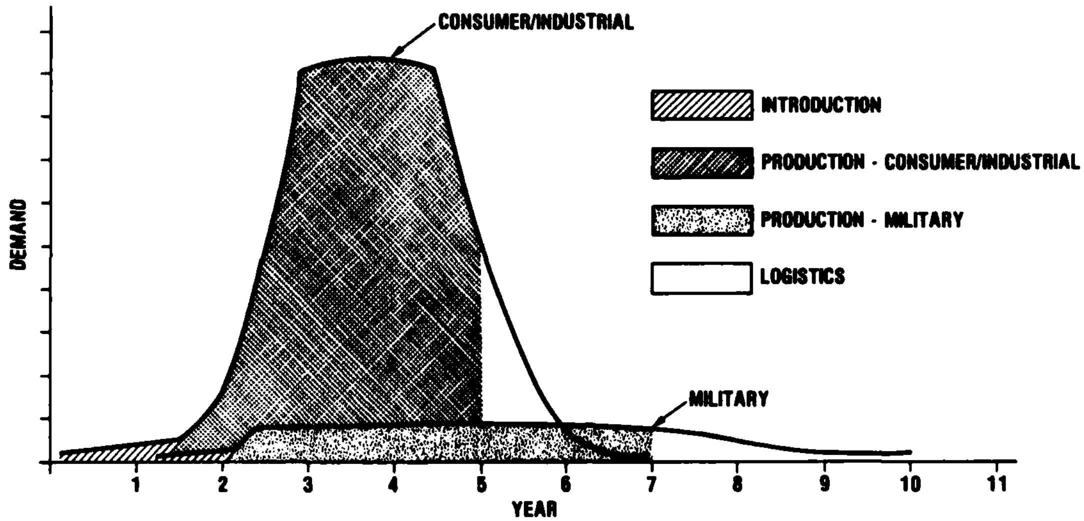


Figure 4. Typical Time Phasing of New Device Designs into the Market Place

Lack of Standardization

Without a standardization program in the front end of a new design, proliferation of different parts types is sure to take place, thereby increasing the number of small lot procurements required for that design.

Special Requirement

Every time an application requires a standard part with special requirement (i.e., 2N2222 with a $BV_{CEO} = 60$ V), it inadvertently necessitates a small lot procurement.

Problems

Once a system manufacturer is forced into a small volume procurement, the problems he faces are many. This paper deals only with the major ones listed below.

Small Volume Procurement Problems

- Schedule
- Cost
- Supplier Follow-through
- Lot-to-Lot Quality
- Qualification
- No Bids

Solutions

Because the small lot procurement problems have been with us for some time, throughout the industry some solutions to these problems have been implemented or suggested. Of course, there are pros and cons to many of these solutions and therefore it is the author's intent at this time to bring these solutions forward so that they may ferment in your mind until the panel discussion on this subject is held this afternoon. If these problems and solutions presented here can be used to form a basis for in-depth discussions on this subject this afternoon, then this paper has fulfilled its purpose. The problems with the corresponding solutions are listed below.

Problem	Schedule and Cost
Solutions	• Pool Procurement • Coordinated Procurement • Common Specification Procurement • Minimum Buy
Problem	Supplier Follow-through
Solutions	• Resident Inspectors • Expedite Orders
Problem	Lot-to-Lot Quality
Solutions	• Physical Destructive Analysis • 100% Temperature Testing at Incoming • Percent Defective Allowed (5%-10%)
Problem	Qualification
Solutions	• Mini-Qualification • Manufacture on Certified Class "S" or "B" Line • Use Supplier "High-Rel Equivalent"

Problem	No Bid
Solutions	• Procure Commercial Devices and Upgrade • Some Type of Centralized Procurement

Recommendations

In order to decrease the impact that the small volume procurement has on schedule, quality, availability and cost, the following recommendations are presented for consideration:

- The military Space community should make provisions for upgrading lower level screened parts (Class "B") for use in Class "S" applications.
- Establish a standardization program that would be accepted by all military Space program offices. This standardization program should include both standard part types and standard screening requirements.
- Microcircuit suppliers should establish a minimum standard baseline for their so-called "equivalent" devices.

PARTS PROGRAM MANAGEMENT

A CRITICAL PART OF
MISSION ASSURANCE

WHAT NEXT?

By

Paul Dick

General Electric Space Division

Summary

This paper presents a summary of General Electric Company Space Division experience on high reliability parts programs, both as a user of these parts in its products, and as an agent for other customers needing such parts and related services. Also presented is our experience with coordinated and integrated parts programs involving many users both international and domestic, including a description of the recently completed DSCS III Program Integrated Parts System (PIPS). The paper then goes into a discussion on the pro's and con's of customers funding contractors for maintaining an inventory of critical parts, subject to possible obsolescence for many production systems beyond those funded. Recommendations for further action are also presented.

Introduction

The ever increasing demands for long-life performance of satellites and space systems continues to dictate the use of the highest reliability parts available for the intended mission or application. Specification integration, procurement, screening and burn-in, acceptance tests and results of other lot related evaluations add increasing delivery times as well as increased costs as the required level of reliability of these devices gets higher. Coupled with the impact of inflation on material costs and raising labor rates, the longer times for delivery of such devices continue to drive hardware costs to higher levels. When bidding on new space programs or follow-ons, contractors must forecast the costs for parts and the related labor based on when the schedule dictates they are needed, which in turn defines when the parts program starts and what phases happen and when. The typical phases of a contractor's parts program include: requirements, specifications, procurement, quality monitoring, product acceptance, and parts control. If the contractor is managing a coordinated procurement for his products and those of his subcontractors, then the various phases noted above get more complex, involving a high degree of integration between the prime and "his partners" on the parts program. The financial advantages, as relates to the materials of an integrated or coordinated parts program, are well known in that unit costs of parts will be lower as the quantity increases and lot charges from several different buyers can be reduced to a singular lot charge on a combined buy. The lot charges noted include those for SEM, data packages, Group B or C tests, DPA, hardness assurance or any other required lot or special selection tests. An added labor savings will also be realized by elimination of certain common activities that are no longer done by the subcontractor(s); the prime does the work for the whole team. These eliminated efforts include: specification integration, order placements, quality monitoring, product acceptance, data books, and management of the lot related test programs by several users of the same items. Another set of benefits of a coordinated or integrated parts program relate to Program Management and Quality Assurance. From a program management basis, greater visability and impact appreciation is obtained when parts are given such top-level attention as results from a coordinated or integrated parts program. Such treatment minimizes the kinds of surprises previously brought to the program office's attention wherein a certain part or parts were: late in delivery, or had failed a screening program, or had not done well in a lot test program such as DPA, or a required reorder for fallouts or a complete replacement lot would require 8 to 10 months for acquisition. These problems, in the form of an integrated parts program approach, are treated quicker and more effectively whether they become problems of the prime or the subcontractors or both. On a quality assurance basis, the integrated or coordinated parts program

assures a common baseline of product uniformity and definition, quality monitoring, acceptance data and traceability, and reduces the overall numbers of different lots and their associated records. It also assures a program of better communications on any parts problems that may develop and an integrated solution basis with appropriate correction action for all users.

Another concept yet to be employed to minimize the initial costs of parts and their potential downstream delivery delay or "problem" costs on a program involves the implementation of an appropriate stocking program of critical, long-lead, or high technology parts needed for forthcoming programs. The advantages is two-fold from such a concept. The most accepted advantage would be program(s) schedule protection as the parts would surely be ready for kitting when needed. On production programs of frozen designs, such a move could foster schedule improvements on "build when contracted designs." In effect, the long-lead or advanced buys portions of some contracts, offers the contractor a head start on getting critical long-lead items ordered. These actions do not in themselves serve the same overall effect of a stocking program. The second advantage of a stocking program is cost savings realized from a combination of buying materials in large quantities and from buying now. The large quantity buys hopefully for many programs usage, drives down unit costs and lot charges. The "buy now concept" is true protection against inflation and potential limited future availability of a given part design. The later case has happened, especially on proven mature designs where a certain integrated circuit or transistor is no longer in production because of limited usage by others, replacement by a more technological product of the producer, or a marketing decision of the producer to no longer market the product for whatever reason. The savings in labor costs for doing 90 percent of the work early and for multiple programs for a stocking program will save the increased labor costs of future years in the areas of Parts Engineering, Procurement Specialists, Quality Assurance Engineers, Test Specialists and other support personnel. A minimal sustaining cost for stock keeping control personnel will be required after the front-end efforts are completed.

An important technical factor in making an appropriate and effective Parts Stocking Program a reality is the establishment and enforcement of a Preferred Parts list. Design Engineers must strive to select their parts from the list as these are the devices that will be stocked. So in reality, the preferred or, as many call it, the Approved Parts List (APL) is the same as the Parts Stocking List (PSL). It is anticipated that as new types or technology parts for future programs are required, they would be added to stock in advance of first-use requirements. This is to say that hopefully the vast majority of part type requirements for a new program will be satisified from stock. Production programs of frozen designs would benefit to the 100 percent mark because all the required part types would be in stock.

As part of the Parts Stocking Program, the storekeepers assigned to this activity would have to keep real-time records on parts issued and parts remaining in stock by part type, purchase order, and lot date codes so that when "minimum reserves" are in stock, an immediate reorder process takes place to replenish the inventory. Minimum reserves criteria would be based on a combination of projected usage, time to replenish an order, and best buy situations. Obviously, the same rules would apply to reorders as initial buys and that is the larger the purchase quantity, the smaller the unit costs and all the other lot related and labor charges that go with the procurement, testing, acceptance, receipt, and stocking.

A very key factor to making the entire scheme work is obviously the financial aspects. This amounts to where the front-end money comes to finance the Parts Stocking Program. Contractors are limited to how much of their resources their corporate structure and stockholders would permit for such an effort without a high degree of assurance of continual program awards by the space hardware customer community. As most new programs are fixed

price competitions, there is no real way of assuring a high degree of awards. A Catch 22 results in that the lowest cost bidder will usually win and a good way to get costs down is to have the parts you need now. But to have the parts you need now requires you to commit a large sum of money, at least one to one and a half years ago for a program that was not then funded, let alone awarded. In the end result, the customer will be paying a higher bill for his products because many potential contractors cannot move out on a Parts Stocking Program without front end financial resources. The question is then raised, "What are the benefits of funding space contractors for maintaining an inventory of critical parts (subject to possible obsolescence) for many space programs beyond those funded?" This is an interesting debate subject and before discussing the pro's and con's later in this paper, a discussion of General Electric experience on Parts Management Programs and a description of the recently completed DSCS III PIPS effort (DSCS III Program Integrated Parts System) follows as it has bearing on the subject matter.

General Electric Parts Management Program Experience

The advent of long-life mission requirements in 1960 (two decades ago) lead General Electric to develop various concepts, practices, personnel resources, and facilities for the specification, procurement, quality monitoring, screening and burn-in, and acceptance of high reliability electronic parts and microelectronics. In the first decade, over two million parts were processed and the recent decade over four million additional parts were processed, a doubling process in just ten years. These parts were used on many in-house programs as well as for the programs of other space contractors who contracted General Electric to be its Parts Management Program Agent. These parts program management customers have been primary international in nature. The General Electric parts experience on U.S. Space Programs is shown in Table 1. General Electric experience on international programs is shown in Figure 1.

As noted in Figure 1, since 1973 General Electric has been providing Parts Management Program services to many European and Asian space companies and consortium. These customers realized the importance of a coordinated parts procurement program from a standpoint of lower unit costs, fewer lot charges and better quality assurance of their parts. They also had to go this route because most of the high reliability parts technology was in the "States" as they called the U.S.A. It was difficult for them to come stateside for the periods of time required for parts work, so they contracted with a major U.S. Aerospace company to be their agent. The U.S. agent then handled the entire contracted program for the delivery to the customer of high reliability parts, related services, and data books defined in the contractual work statement. Figure 1 details some of these programs, geographical locations, and quantities of parts delivered. On the tabulation is the Nimbus-G Unified Parts Procurement Program (Item 4 in Figure 1) geographically l[illegible] at NASA-GSFC on the map. This Parts Management Program was an effort wherein General Electric coordinated the parts program for a total of nine different NASA-GSFC funded experimenters who provided payloads on the Nimbus-G spacecraft. The users were located throughout the U.S.A. (Ball Brothers, JPL, GD-Orlando, RCA, Honeywell-Lexington, Massachusetts, and University of Wyoming) and Oxford University in England, as well as NASA-GSFC who stocked all the program spares resulting from the NUPPS (Nimbus Unified Parts Procurement System). This was our first "on-shore" coordinated parts procurement program, even though, as a prime contractor for many years, we managed our own parts for designs, such as Nimbus, OAO, Landsat, Mariner, Moon Based Power Supplies, Viking, BSE, and the other programs shown in Table 1. As it turned out, NASA-Goddard had requested General Electric to pick up the parts management role for the experimentors who, if they had each done singularly what they proposed, would have run the costs of the same parts for their designs considerably higher. Tables 2A and 2B show a comparison of the material cost savings and total savings on the Nimbus-G Unified Parts Procurement Program.

The next section of this paper covers recent AF-SD Parts Program Experience.

Recent Parts Program Experience on the DSCS III Program

As part of the DSCS III Phase 2 program, which is a fixed price contract with AF-SD, General Electric planned, implemented, and managed a Program Integrated Parts System, called PIPS. The PIPS work flow is shown in Figure 2. A detailed snyposis of the scope extent of PIPS is shown in Table 3. From the standpoint of statistics, almost 500 types of different parts were procured from some 90 different parts manufacturers; almost 5,000 line items were ordered; almost 400,000 discrete parts were screened, burned-in, and acceptance tested; over a quarter million active devices received on-site, precap visual inspections as part of the Quality Monitoring Program as shown in Table 4.

Over 500 lots of active devices received lot sample radiation tests (flash X-ray, neutron and gamma radiation exposures); almost 30,000 Junction Isolated Integrated Circuits were given latch-up tests. More than 50 hybrid circuit types and 10 small integrated component types were also subjected to screening and burn-in, acceptance tests, and radiation tests.

About 95% of the parts were supplied by General Electric to the users of PIPS. The reason the number was not 100% was because the basic rule of PIPS was that a part would be supplied from PIPS if it met one of the following criteria:

- Was used in any design provided by the prime
- Was used in any design of at least two users, i.e., GE and another subcontractor or two subcontractors
- Was being provided at a subcontractor's request because he did not have the capability to do the procurement himself
- Was being provided to the subcontractor to protect the product delivery schedule either at his request, or contractually agreed during negotiations with the subcontractor
- Was a high technology item which General Electric produced, such as a hybrid circuit or needed GE expertise to define, procure and acceptance test such as a GaAs Field Effect Transistor

Several typical hybrid circuits produced at GE are shown in Figure 3. From a review of the above factors, resulted a small residue of parts which fell into the following categories:

- A given subcontractor(s) was the only user of a certain part type. An example would be a very high ohmic resistor.
- A given subcontractor(s) was responsible for building that device as part of his particular product design; examples include magnetics, transformers, chokes, etc.
- A given subcontractor required a part already on PIPS but with a special selection factor above and beyond that required by the other users. There were only three such cases, each of which were handled separately.

The above items were handled by the responsible subcontractor subject to the parts program requirements described in applicable pass down requirements documents traceable to SAMSO Standard 73-2B and the approval of the PMPCB-Parts, Materials, and Processes Control Board. The PMPCB composed of representative from AF-SD, RADC, DESC, Aerospace, AFPRO, and GE as well as subcontractor representatives when required meet over 20 times during the DSCS III Phase 2 program to discuss and act upon parts activities such as: specification reviews and approvals, DPA results, screening results, LAT results, problems and corrective action, and PIPS status.

The PIPS effort did not have a precontract

Parts Stocking Program (PSP) phase as the design was not fully defined at that point and the choice of a contractor was not established until completion of a competitive Program Definition Phase, and the amount of funds for such an effort were not available in the offers of the contractor. As a result, the PIPS effort spanned a significant part of the program span. A properly managed Parts Stocking Program could have reduced this time cycle on the Phase 2 contract and would significantly reduce the delivery cycle of production units in the Phase 3 effort.

Pro's and Cons of a Parts Stocking Program

As previously discussed in this paper, a Parts Stocking Program requires the establishment and disciplined use of an Approved Parts List by Design Engineers. The Approved Parts List defines what items are to be stocked and future anticipated needs establish how many of each of the items on the Approved Parts List will be maintained in stock. This then defines the materials dollars required and the corresponding labor dollars to be spent to establish the initial inventory of parts. Real-time records of parts issued from inventory and the balances remaining by part type will trigger the reordering process when minimum reserve quantities are obtained in stock.

While the cost savings to future new programs or follow-on production contracts can be easily shown to result from appropriate Parts Stocking Programs which is a "Pro" for such an effort, the "Con" is: "Where does the front end money come from to finance the effort that will ultimately pay for itself many fold?" The Catch 22 comes into play as noted earlier, unless the end customer(s) helps the space contractors with financial aid.

The financial benefits to the government, which accounts for both NASA and AF-SD Space Projects, of providing funding to space contractors from maintaining an inventory of critical parts for many programs beyond those funded, can be substantial. The parts to stock must be those applicable to such space projects and as such factor in those parts on PPL-14 for NASA, AF-SD's preferred parts list of MIL-STD-1546 and MIL-STD 1547 and approved parts on the lists from other users like JPL and those parts on the DESC-AQL's as appropriate. With the future widespread implementation of the Class "S" lines per MIL-STD-1546 and MIL-STD-1547 and the AF-SD commander's Policy on Parts of 1978, it becomes more imperative that space contractors prepare and propose their listings of approved Parts Lists for long-life Space Programs to their customers for approval and use these as the basis for planning a Parts Stocking Program. Approval of these listings by various customer houses, such as AF-SD and NASA centers, and the issuance of funding from these houses to space contractors to pay a fair share portion of the effort will go a long way to making Parts Stocking Programs an effective reality.

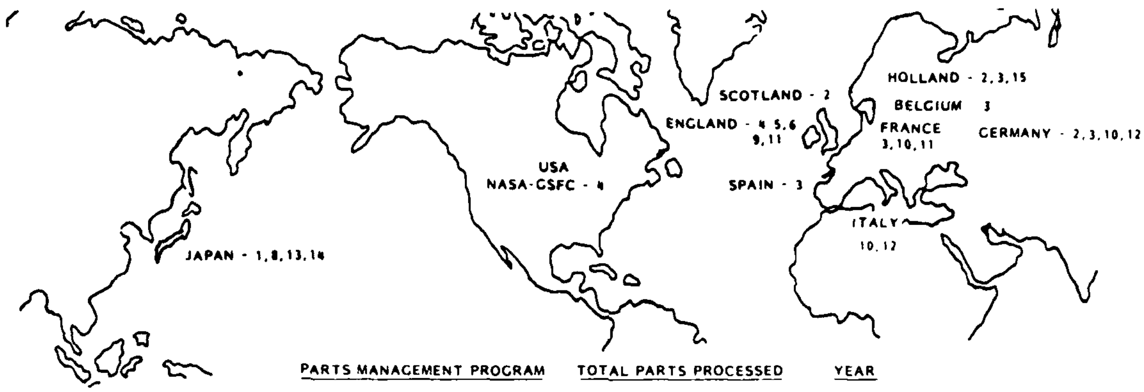
The end result of such actions can only save precious dollars and improve and protect delivery schedule of end products. In a sense, the thought is similar to the one given by the gasoline station mechanic who, in that famous TV commercial says, "You can pay me now or pay me later." The point to be made is to do it now.

Conclusions

Based on General Electric's experience with coordinated and integrated parts programs and the state of the marketplace on parts, Parts Stocking Programs offer definate cost advantages above and beyond those already being realized from the coordinated and integrated parts program efforts.

Recommendations

The Customer Community for Space Parts (AF-SD and NASA Centers) together with the Space Contractors and Parts Producers should form a small ad hoc Study Group under government chairmanship to establish the plans and mechanics and recommendations for effecting Government Funding assistance programs for Space Parts Stocking Programs by Space Contractors. This Mission Assurance Conference offers a good place and time to kickoff such an effort. We at General Electric Space Division are available, and I am sure other contractors are also available, to discuss this program further.



PARTS MANAGEMENT PROGRAM	TOTAL PARTS PROCESSED	YEAR
1. ETS III	40,000	1978 1980
2. IRAS	40,000	1977 1979
3. SPACELAB	285,000	1976 1979, 1980 1982
4. NIMBUS G	120,000	1976 1978
5. MAROTS	35,000	1975 1978
6. SSU	20,000	1975 1976
7. IUE	40,000	1975 1976
8. CORSA	32,000	1975
9. METEOSAT	10,000	1974 1975
10. ECS	38,000	1974 1975
11. SKYNET III	80,000	1973 1974
12. OTS	50,000	1974 1975
13. ISS	30,000	1974
14. HAS	25,000	1974
15. ANS	49,000	1973

Figure 1. GE Experience on International Programs

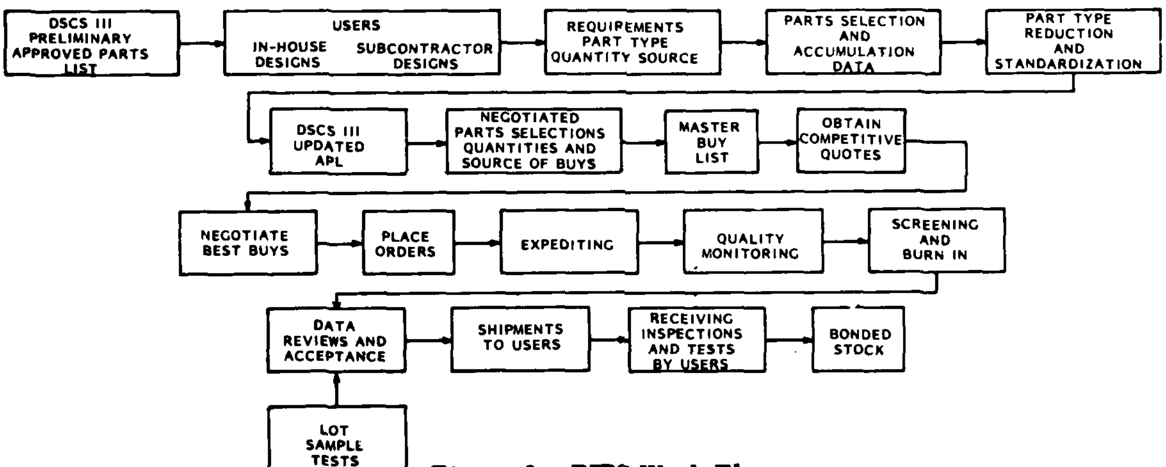


Figure 2. PIPS Work Flow

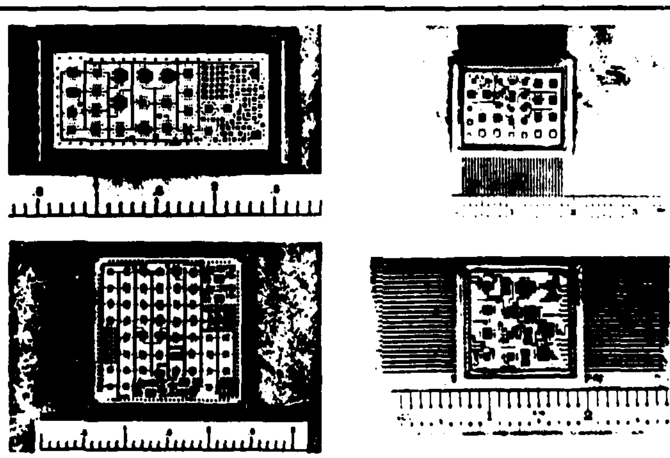


Figure 3. Typical GE Hybrid Circuits

NASA Programs

Apollo	Mariner	Sisyphus
ATS	Nimbus	Skylab
Biosatellite	OAO	Space Shuttle
Landsat (ERTS)	OSO	Viking Orbiter

Military Programs

Advent	LES 8/9
Classified	Minuteman
DSCS III	MOL
GGTS	NRL
GPS	Trident

ERDA Programs

SNAP-27	MHW-RTG	MJS-RTG

Table 1. GE Parts Experience on U.S. Space Programs

How much can be save on an Integrated Parts Program? - A Case History
Nimbus-G Unified Parts Procurement Program - Material Cost Analysis

	Line Items		Parts Quantity		Materials-K $	
	UPPP-Mgr	6 Users	UPPP-Mgr	6 Users	UPPP-Mgr	6 Users
Microcircuits	105	267	14,344	9,356	645.3	756.8
Transistors	34	98	4,943	3,766	56.9	65.5
Diodes	69	134	11,480	9,123	81.7	93.2
Relays	9	21	599	436	55.4	61.2
Capacitors	214	367	13,420	11,622	66.5	93.5
Resistors	964	1,612	26,212	23,210	52.2	76.7
Connectors	58	96	1,220	993	21.8	22.2
Other Misc.	27	47	2,771	2,065	66.6	71.1
TOTALS	1,480	2,642	74,989	60,571	1,046.4	1,240.2
Materials. Average Unit Cost					$13.95	$20.48

(32% Average Unit Cost Savings)

More Parts for Fewer Dollars and Schedule Protection

Table 2A. Parts Program Savings Materials

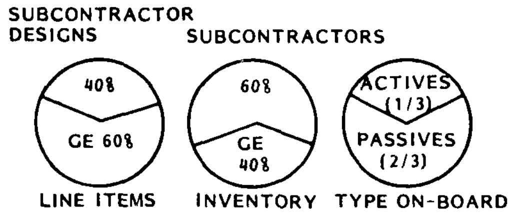
Nimbus-G Unified Parts Procurement Program
- Total Cost Material

	6 Different Users Each Manage Their Parts Program	Unified Parts Procurement Program Management	Unified Parts Procurement Program Management
	Cost	Cost	Cost Savings
• Specification Preparation	$ 168.3 K	$ 100.7 K	$ 67.6 K
• Procurement/ Expenditing	266.3	114.4	151.9
• Precap Inspections	34.6	14.4	20.2
• Acceptance Inspection and Test	218.2	209.7	8.5
• Materials (Table 2A)	1,240.2	1,046.4	193.8
• UPPP Integration	--	1,116.0	(116.0)
Totals	$1,927.60	$1,601.60	326.00K
Total Savings			$ 326.00K

Savings in Labor and Materials Dollars are Significant

Table 2B. Parts Program Savings, Total Costs

- User identifies parts needs to prime contractor
- Prime contractor consolidates, standardizes and integrates requirements with users
- Prime contractor specifies, orders, expedites and delivers all common usage parts for 13 subcontractors making 21 different products, in addition to parts needed by prime for his designs



- *Significant cost reductions*
  - Unit costs less
  - Fewer lot charges
  - Elimination of duplicate labor efforts
  - Reduction of travel and living costs
- Uniform quality program
  - Common process reviews and surveys
  - Fewer sources of supply
  - Greater traceability of data
- Schedule maintenance
  - Timely ordering
  - Program management visibility
  - Early problem resolution

Table 3. PIPS Scope

Part Type	Number Of Lots	No. of Parts Accepted by Manufacturers	GE Precap Inspection Results (CSI) No. of Parts Accepted	No. of Parts Rejected	Percent of Rejections
Diodes	145	94,183	92,765	1,418	1.50
IC'S	681	133,639	130,238	3,401	2.54
Transistors	105	26,750	26,299	451	1.68
Total Actives	931	254,572	249,302	5,270	2.07
Capacitors	19	2,223	2,190	33	1.48
Crystals	20	250	246	4	1.60
Filters	8	2,479	2,463	16	0.64
Relays	53	5,742	5,558	184	3.20
Total Passives	100	10,694	10,457	237	2.21
Other	51	2,121	2,034	87	4.10
Grand Totals	1,082	267,387	261,793	5,594	2.09

Table 4. Precap Visual Inspection Results

MANAGING THE DEVELOPMENT AND PROCUREMENT OF HYBRID PARTS

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ROCKWELL INTERNATIONAL

Introduction - This presentation will deal briefly with considerations to be addressed when hybrid parts are to be used in electronic systems/subsystems. The issues to be addressed are as follows:

- When are system/subsystem management techniques appropriate for a hybrid procurement?
- What types of trade-offs are to be evaluated in the decision to use hybrid parts?
- What types of management controls are needed for hybrid procurements?
- How can test capabilities be fully utilized in hybrid procurements?

The actions suggested herein have in most cases been used in actual procurement programs, or are those which experience has shown would be desirable for implementation on new programs. They are not intended to delineate specific technical requirements, but to act as signposts along the development/production path.

The usage of hybrid parts, usually but not always in the form of microcircuits, has become increasingly popular in system design. Consideration of the density of circuit elements that can be accommodated in a typical hybrid almost begs the question of whether or not a hybrid should be considered as a subsystem. Circuit partitioning of a system into a group of hybrids almost always results in the definition of functional blocks (or subsystems) of a system, and these hybrids historically require management as subsystems.

The cost trade-offs that are performed in the determination to use hybrids are of the usual kinds: Weight/volume, time, and funds. The weight/volume tradeoff can be approximated from a conservative baseline of approximately 47 circuit elements per square inch of hybrid substrate area. System penalties associated with weight/volume can usually be readily assessed. The trade-offs in time center around the efforts for system partitioning, hybridization feasibility, prototype development/test, element procurement/test, and hybrid production/test. The funding tradeoffs are subtle, and related to the system contractor's capability in the areas of design, production, and test as related to hybrids; the required quality level of parts for the system and the prevailing parts market situation are also factors. Realistic consideration of these tradeoffs is not at all straightforward, and the deciding factor is usually the most inflexible requirement of the contract specification for the system. Discussion of a typical tradeoff issue is presented in Figure 1.

The management controls required for development and procurement of hybrid parts are, fortunately, not unique. Particular emphasis should be focused in three areas: hybrid specification, supplier evaluation, and project monitoring. A brief review of each of these areas of management control will highlight some concerns.

Specification - The first fact to be realized is that there is no existing, coordinated specification that can be used as-is for hybrid procurement. The system must be partitioned into functional hybrids and approved through the normal rigor of design review. Performance tests must be defined, and test software developed. Although it is not usually desirable to define a particular hybrid fabrication process in the specification (because it may lock out many potentially good hybrid suppliers), certain basic process constraints that have a bearing on process yields should be defined; for example, items such as allowable rework, delidding, coatings, organic materials, metal joining systems, and sealing techniques should be addressed. Screening tests, both in-process and as final

acceptance, may need to be uniquely defined for hybrids; examples might be die-bonding and wire-bonding in-line testing, water vapor content in sealed units, electrolytic stress tests, particle noise tests, pre-seal burn-in tests, thermal mapping tests, and operational temperature cycling burn-in. The qualification of the hybrids occurs in essentially two phases; the verification of the circuit design, and the assessment of the hybrid fabrication process. The circuit verification should largely be accomplished before the major hybrid production is committed, and is generally done via breadboard and prototype hybrid tests. Hybrid fabrication process assessment and certification can be accomplished in piecemeal fashion to a large extent, in that each production process can be evaluated independently, and also as a series of in-line production tests. As a minimum, the objective evidence required by the Product Assurance Program of Appendix A of Mil-M-38510 should be imposed. The specification should require a process baseline definition, and approval by the buyer of any proposed process changes (this also implies an objective evaluation and approval by the buyer of any reasonable proposed change, when supported by sufficient test data). The element/circuit derating criteria should be included in the specification, and a detailed thermal analysis should be required. Finally, the degree of process, material, and element traceability for the hybrid should be defined by the specification.

Supplier Evaluation - Whether the hybrid supplier is an outside vendor (usually a specialty house) or an in-house facility (generally dedicated), an objective evaluation of supplier capabilities must be performed. The initial step is to evaluate the capability to produce the volume of hybrids in the allotted schedule time. This can be approximated by determination of total circuit element population, including wire bonds, and comparison of these populations to the demonstrated thru-put rates of the supplier (inspection thru-put rates are also essential in this evaluation). The testing rate for both electrical and environmental tests, and the anticipated yields must also be factored into the overall assessment. It is a mistake to believe that capacity can be quickly and easily expanded, even for a mature and proven process. Next, the technical capability of the supplier must be evaluated, both in terms of circuit design and process compatibility. These two factors are interrelated, in that the supplier may be able to compensate for his process characteristics by circuit design alterations; he should be able to demonstrate by test data the characteristics and tradeoffs associated with his process and materials. Offers to implement the buyer's design with non-mature processes/materials should be approached with extreme caution. In line with this consideration, the supplier should be able to demonstrate by production and test data the maturity of his standard process, and its expected yields. Incredible as it may seem, many suppliers do not understand their own processes well enough to demonstrate such proof. If the supplier is being considered as a second source for a qualified hybrid, careful consideration must be given to the compatibility of his process with respect to the hybrid design. Such innocuous differences as wire bonding techniques, process temperatures, package seal techniques, and package plating may have far reaching effects on a particular hybrid circuit's performance and reliability. An example of problems actually associated with a multiple source procurement is shown in Figure 2.

Project Monitoring - If the procurement of hybrids is not second-sourced, adequate project monitoring is required to anticipate and circumvent the problems that are typical with most hybrid projects. Schedule problems are almost endemic, and are related to such things as extended

delivery on semiconductor elements, element lot evaluation/acceptance problems, rework, "black-art" fabrication problems, and the "ever popular" equipment downtime. If any management control or influence is to be realistically exercised on a hybrid production contract, it is essential that a real-time reporting system of work-in-progress and yield (or thru-put) be established with the hybrid supplier. Experience has shown that an effective method is to require reporting of all inspection actions on the hybrid production line on a weekly basis (see Figure 3). Additionally, the requirement for analysis of failures and institution of corrective action should be required at the earliest possible point in the hybrid manufacturing cycle. The long lead times for hybrids, coupled with the system assembly/test times, make it unrealistic to assume that any meaningful in-line corrective action can be made in hybrid processes if the user waits for box-acceptance tests and/or field failures to trigger the change actions. It has been found cost-effective to replace the requirement for destructive physical analysis of hybrids with customer/government source inspection; this action also allows for a more effective chance to institute in-line corrective actions on the questionable hardware/process. The final monitoring point would obviously be cost/hours on a contract other than fixed price.

A final comment on possible improvements in test capability appears to be in order. The thru-put of hybrid production can of course be greatly enhanced by the standardization of the functions to be hybridized, and by allocating as much testing as possible to not only standardized ATE, but to test programs associated with laser resistor trimmers. The thru-put rate of these types of equipment is quite high, and should be used to the maximum extent on any hybrid procurement. In addition, the use of functional trimming can in many cases alleviate long lead time problems on procurement of precision resistor arrays and exotic functional semiconductor devices.

In summary, it is recommended that all except the very simple, off-the-shelf hybrid procurements should be the subject of stringent management attention/techniques that are more commonly associated with subsystems.

EXAMPLE OF TRADE-OFF CONSIDERATIONS FOR HYBRID USAGE

ISSUE: PART REPLACEMENT AT BOARD/BOX LEVEL

<u>ITEM</u>	<u>DISCRETE PART</u>	<u>HYBRID PART</u>
REPLACEMENT COST	LOW TO MEDIUM	MEDIUM TO VERY HIGH
REMOVAL DAMAGE RISK TO BOARD	LOW	LOW TO HIGH
ANALYSIS OF REMOVED PART	NO REWORK AT PART LEVEL; PERFORM ANALYSIS.	TROUBLESHOOT TO ELEMENT (PART); DECIDE WHETHER TO REWORK HYBRID, OR SACRIFICE HYBRID TO ANALYZE ELEMENT.

EXAMPLE OF MULTIPLE-SOURCE PROBLEMS

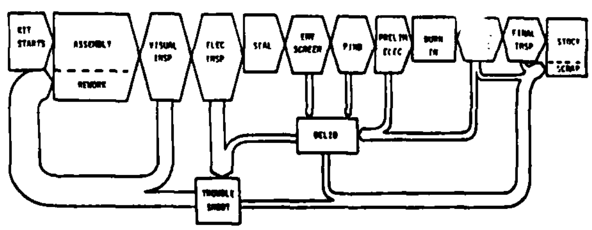
- <u>ORIGINAL SOURCE</u>
  - LOW TEMPERATURE GOLD ULTRASONIC BALL BONDING
  - THICK FILM GOLD SUBSTRATE METALLIZATION
  - EPOXY SUBSTRATE ATTACHMENT
  - VACUUM BAKEOUT THRU SEAL WITHOUT EXPOSURE TO ATMOSPHERE
  - DIE ACCEPTANCE VIA CANNED, WIRE BONDED SAMPLES
- <u>SECOND SOURCE</u>
  - THIN FILM TITANIUM-PALLADIUM-GOLD SUBSTRATE METALLIZATION
  - EPOXY SUBSTRATE ATTACH MANDATED; NORMALLY USED SOLDER
  - VACUUM BAKEOUT FOLLOWED BY ATMOSPHERIC EXPOSURE PRIOR TO SEAL

  <u>PROBLEM</u> - CONTAMINATED, MOISTURE-LADEN HYBRIDS EXPERIENCED SHORTS DUE TO GOLD DENDRITES AT BOX-LEVEL THERMAL TESTS
- <u>THIRD SOURCE</u>
  - ALUMINUM ULTRASONIC WEDGE BONDING
  - 100% DIE PROBE TESTING FOR ACCEPTANCE

  <u>PROBLEM</u> - CRATERED TRANSISTOR DICE UNDER WIRE BONDS EXPERIENCED FAILURES AT BOX-LEVEL TESTS AND IN FIELD USAGE

TYPICAL PRODUCT FLOW FOR HYBRID ASSEMBLY

- HEIGHT OF BLOCKS IN PRODUCT FLOW LINE IS INDICATIVE OF THRU-PUT
- TYPICAL ANNOTATIONS FOR EACH BLOCK WOULD INDICATE:
  - UNITS TO STATION PER WEEK
  - UNITS REJECTED PER WEEK
  - STATION YIELD (%) PER WEEK



MANAGEMENT APPROACH TO HANDLING

CUSTOM LSI

w. Richard Scott
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Jet Propulsion Laboratory

As defined by Meriam Webster, the term, 'approach' implies the taking of highly individual, preliminary steps toward a particular purpose. The approach we are taking in an on-going custom LSI program at JPL, while it may be a specific set of steps toward a particular purpose, may still be applicable to your organizations and for that reason I would like to share with you some of the experiences from which we have learned and are still learning. Following this "Share and Tell" I would like to discuss some new approaches we are studying at JPL to make future custom LSI programs more successful.

BACKGROUND

In order to understand our approaches we need to examine the kinds of programs which we are supporting at JPL. JPL has been given by NASA the prime responsibility for NASA's unmanned, planetary spacecraft programs. Since the 1960's, JPL has been responsible for the Ranger, Surveyor, Mariner and Viking programs, which sent spacecraft to, past, or orbiting about the Moon and Mars as well as Venus and Mercury. More recently we conducted the dual-spacecraft Voyager program whose spacecrafts encountered Jupiter last year, will reach Saturn in about seven months and fly by Uranus in 1986. The Voyager was designed to meet requirements of several years of operational life, long-range communications (400 - 1700 million miles), precision navigation, solar-independent power, resistance to the radiation fields of Jupiter, and to provide in-flight reprogramming capability to support the science investigations. JPL is presently developing the Galileo spacecraft which will be launched in 1984. This mission begins with a 1000-day journey to Jupiter followed by a 20-month orbital tour of Jupiter and its moons. If the spacecraft survives for this period, as is expected, an extended mission could then continue to explore the environment of the planet. Recognizing the long-life, non-maintainability requirements of JPL's spacecraft programs, should put our custom LSI activities into proper prospective.

SELECTING LSI

There are a number of choices available to designers who wish to use LSI, including 1) handcrafted off-the-shelf microprocessors (1802, Z80, 6800, Z8000 and 680000) together with their support chips; 2) standard cell custom LSI; 3) custom gate arrays; and 4) structured design custom LSI. Each has its place, its advantages and disadvantages.

On Project Galileo, JPL selected the first approach, the off-the-shelf microprocessor. However, we did not stop there. Our spacecraft design demanded a low power, radiation-hard microprocessor. These conflicting requirements led to the selection of the low-power CMOS technology which, in turn, pointed directly to the 1802 microprocessor family. While the 1802 was not radiation hard, Sandia Laboratories had already begun a program of hardening this RCA device family. How fortunate for JPL, a rad-hard, low-power microprocessor. And it looked like we were home free. But were we home and was it free?

We think our choice of the Sandia-modified, RCA-designed 1802 LSI family was a wise selection and eventually will be proven sound. But our pathway has been full of obstacles and knowing of these obstacles may make your stroll down the custom LSI road a little less hazardous.

WARNINGS TO THE WISE

Custom LSI procurements are often by nature sole source. With that comes the many problems which make sole source risky for any procurement -- the runaway costs and uncontrollable schedules as the manufacturer learns how the customer's requirements push the state of the art; lack of an adequate back-up position; changing quantity requirements; and many more. A truly custom device usually implies that there has been no previous

physical evaluation or electrical characterization, much less qualification. So the user doesn't know what the device specification really is -- only what it is targeted to be. With this comes the added need for increased technical staffing, both be the device manufacturer as well as the user. Staffing to be applied to the task of studying the device in detail sufficient to recognize its shortcomings, understand their impact on the hardware design, and assess the potential risks.

Also, because this is a custom device, the manufacturer has not fabricated it in sufficient quantity to verify his design nor work out his fabrication start-up problems. Additionally, the design engineers must be prepared to accept and deal with the inevitably reduced performance and reliability characteristics. They must design tolerant and perhaps redundent systems which are capable of operating at reduced voltage levels and speeds.

In the present semiconductor market, it is difficult, if not impossible, to persuade the semiconductor manufacturer to make the necessary heavy committment to an area of such marginal profit. And to make this committment for him, as in the case of Sandia in the Sandia/RCA radiation hardening program, you are still left with the enormous problem of the technology transfer from the research and development laboratory of one company, to the production facilities of another.

We at JPL have experienced various degrees of all of these above problems. And, only working the "Human Equation" as stated yesterday by General Henry, through the deep personal committments of many JPL, RCA and Sandia personnel will we ultimately succeed in this custom LSI program, but not without having paid a high price, a price measured not only in dollars but also in lost sleep, weight and a lot of other scarce resources.

THERE IS A PLACE FOR CUSTOM LSI

We are finding that the use of off-the-shelf LSI, such as the 1802 microprocessor, requires inordinate amounts of small scale and medium-scale integrated circuits for various interface functions which could be easily implemented in one to two custom chips. In the Galileo design, for instance, one such interface function requires on the order of forty off-the-shelf chips.

In the far term, we see in our applications, the need for processing at throughput rates orders of magnitude greater than those presently available with conventional microprocessors. For example, construction of geometrical images from snythetic aperture radar data in real time requires over ten billion complex operations per second.

A CUSTOM LSI PROGRAM

Driven by these near and far-term requirements, we are developing at JPL what we call our "Custom-LSI Headstart Program" (CHP). Under this program we are educating design engineers in the fundamentals of semiconductor design; developing the computer design aids necessary to design custom LSI devices; establishing wafer fabrication sources; and developing a product assurance approach which will assure that the resultant custom LSI is free of workmanship defects and is reliable enough for spacecraft applications.

Under this program designers are trained by their participation in a design course based on a course currently offered at Caltech by Professor Carver Mead. The course teaches the fundamentals of structured design at the patterning level and encompasses both theory and "hands-on" experience. Each student has the opportunity to design his own LSI circuit, have it fabricated, and then test it.

The second goal of the headstart program is to develop the tools and the capability for computer aided design of custom LSI. This requires developing some new hardware and software as well as interconnecting the CAD facilities at JPL, NASA, the Army, Sandia Laboratories, and others in order to facilitate access to these newly developed design aids.

The third goal, that of establishing wafer fabrication sources and controls,

calls for developing an approach to fabrication which separates the circuit design from the fabrication process. The designer bears the full responsibility for the design of a functional circuit which will meet all his system requirements. The fabrication facility, in turn, is charged with the responsibility of fabricating the circuit using fully controlled process steps. JPL is presently developing test chips which, through appropriate electrical stresses and measurements, may be the means for accepting or rejecting the wafers from the fabrication organization.

Lastly, the CHP is developing a product assurance approach. If we are to fly custom parts, we must learn to qualify them. It does not appear that this can be accomplished merely by testing the finished product. We are studying various approaches to the qualification process including: requiring ultra conservative design rules; designing in circuit testability; completing significant portions of the device qulaification in conjunction with the device design verification; using test chips to accomplish other portions of the qualification process; and finding other techniques to replace some of the classical qualification procedures.

TEST CHIPS CAN BE HELPFUL

Along this line we are currently evaluating the capabilities of various test chip structures to provide direct measures of die-related failure modes such as: surface contamination; defects in the crystal structure, oxides and passivation layers; and doping, mask and metallization faults. We are also evaluating test chip electrical test data for correlation with packaged device electrical test results. Our goal is to design test chip structures and define electrical measurements on those structures with which we can predict which semiconductor wafer runs will not stand up to the rigors of acceptance testing or qualification testing. If we are successful in this endeavor, we will be able to reject devices at the wafer stage which otherwise would not be rejected until after weeks and even months of assembly, packaging, and testing.

CONCLUSION

Using custom LSI devices in today's environment can and does carry with it many problems and I have tried to enumerate some of these from our own experiences at JPL. But there are valid and compelling reasons to consider the use of custom LSI in new hardware designs, designs in which the available off-the-shelf devices do not meet the system functional requirements. And finally to better meet the reliability challenges of custom LSI devices, JPL is developing its Custom-LSI Headstart Program. It is only through such a system approach to LSI design, fabrication, and qualification that we feel custom LSI will ever be achievable, available and acceptable for high reliability applications.

EXPLORATION OF THE PLANETS

- Moon
  Ranger
  Surveyor
- Venus - Mercury
  Mariner
- Mars
  Mariner
  Viking
- Jupiter - Saturn - Uranus
  Voyager
  Galileo
- Sun
  International Solar Polar Mission

LSI SELECTION OPTIONS

- Off-the-shelf
- Standard Cell Custom
- Custom Gate Arrays
- Structured Design

INHERENT PROBLEMS WHEN USING CUSTOM LSI

- Sole source procurement
- Runnaway costs and schedule
- Back-up device
- Characterization
- Qualification
- Specification
- Technical Staffing
- Manufacturing start-up problems
- Reduced performance
- Technology transfer

THERE IS A PLACE FOR CUSTOM LSI

- To meet basic requirements
- Interface functions
- Throughput rates beyond capability of conventional devices

CUSTOM - LSI HEADSTART PROGRAM (CHP)

- Educating Custom LSI designers
- Developing CAD
- Establishing wafer fabrication sources
- Product assurance approach

CUSTOM LSI QUALIFICATION PROCESS

- Ultra conservative design rules
- Designed in testability
- Device design verification
- Test chips

TEST CHIPS

- Surface contamination
- Defects (crystal, doping, and passivation)
- Faults (doping, mask, and metallization)
- Predictor of electrical and functional rejects

CONCLUSIONS

- Expect problems
- Valid need for custom LSI
- System approach

SUMMARY OF ISSUES AND RECOMMENDATIONS

THE MANAGEMENT AND PROCUREMENT OF PIECE PARTS

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Small Volume Procurement

Issue

Programs and contractors have difficulty getting space quality parts in small volume at reasonable cost and schedule.

Recommendations

- o USAF/SD in coordination with NASA, investigate acceptable methods of up grading lower level screened and Class 'B'' qualified parts for use in applications requiring Class ''S'' devices that are not on the qualified products list.

- o USAF/SD and NASA examine techniques for strengthening standard implementation of parts technical requirements across projects.

2. Class ''S'' Parts Program

Issue

Class ''S'' market volume requirements are small-manufacturers are not motivated to certify, qualify, and accelerate production and reduce lead times.

Recommendations

- o USAF/SD and NASA and industry jointly accelerate efforts to better standardize on space quality parts requirements across a broader set of users.
  - SD programs
  - Com Sat
  - NASA space flight programs
  - Other space part users

- o USAF/SD and NASA develop methods to maximize ease of procurement of standard space quality parts, e.g.,
  - Stocking by gov't or prime
  - QPL listing
  - Wafer banking
  - Long lead funding

3. Custom LSIC

Issue

Custom Large Scale Integrated Circuit (LSIC) and hybrids can introduce more cost, schedule, and reliability risk than standard LSIC and hybrids.

Recommendations

- o USAF/SD and NASA should assure that programs conduct sufficient evaluations and volume/weight implementation tradeoffs to justify the use of custom LSIC and hybrids when the design could be implemented with standard parts.

4. Management of LSIC

Issue

Classifying custom Large Scale Integrated Circuits (LSIC) and custom hybrid microcircuits as parts subjects them to ''parts'' controls that may not be adequate or appropriate for these ''system-like'' devices.

Recommendations

- o USAF/SD and NASA should assure that custom LSIC and custom hybrid development and procurement includes appropriate system level controls as well as appropriate parts controls through management and technical documentation.
  - Design Review
  - Qualification
  - Software
  - Screens
  - Application

CONCLUSIONS

1. Small Volume Parts Procurement

   - Still plague space programs

     - Special project requirements are a major cause of small volume buys.

   - Cause cost, no bid, reliability problems.

   - As Military/Aerospace market percentages decrease small volume procurement commands less attention by vendors.

   - Lack of firm market forecast for space quality parts further decreases producer motivation.

   - Coordinated or pooled procurements offer partial solution to small volume procurements and are encouraged by USAF/SD, NASA and space contractors.

2. Coordinated Procurement

   - Sev ral different approaches used - varying degrees of task centralization.

   - Offers cost, schedule and reliability advantages.

   - Requires more in-depth management.

   - Avoid detailed specification of coordinated procurement requirements in contract. Let contractor explain approach in proposal.

   - Schedule liability is a major concern in implementing coordinated procurement.

3. Management of Large Scale Integrated Circuits (LSIC) and Hybrid Microelectronic Devices

   - The demand for custom LSIC and hybrids is expected to increase to meet future space system requirements.

   - Custom LSIC/hybrids introduce more cost, schedule and reliability risk than standard LSIC/hybrids.

   - There are characteristics of LSIC and hybrid devices that are not currently covered by space quality part requirements.

   - Hybrid microcircuits are both parts and assemblies/subsystems and must be managed as both.

WORKSHOP E

E-2 PARTS – THE NEW DEVELOPMENTS IN MICROELECTRONIC TECHNOLOGY (cont)

Chairmen	Coordinator
Validation and Verification of LSI Technologies and Design Tools	Case J. Van Leeuwen Harris Semiconductor
Command Data Subsystem for the Galileo Orbiter	Wayne Kohl, JPL
Bit Slice Influence on Spaceborne High Throughout Processor (HTP)	Lewis Bonilla, Hughes
COMOS/SOS High Performance Processors for Future Spaceborne Missions	Alba Cornish, Stan Ozga, and James Saultz, RCA
Impact of LSI on Spacecraft Architecture	Phil Holt, Aerospace Corporation

LUNCH

Overview of Workshop Sessions

- Summarize Positions
- Discuss Alternatives
- Review of Recommendations

WORKSHOP E

E-2 PARTS – THE NEW DEVELOPMENTS IN MICROELECTRONIC TECHNOLOGY

Chairmen	Coordinator
Dr. Jack Hilibrand Staff Technical Advisor RCA Government Systems Division	Allan Carlan The Aerospace Corporation
Carl M. Lekven Manager, Space Computer Section The Aerospace Corporation	
Robert E. Covey Manager, Electronic Parts Engineering Jet Propulsion Laboratory	

Micro-Electronics Requirements for Commercial Satellite Application	Irwin Feigenbaum Comsat Laboratories
Current Status of, and Projections for the Class S Space Parts Program	Jim Egan, Aerospace Corporation
Space Radiation Effects and Cosmic Ray Induced Upsets in Modern Semi-Conductor Devices	William Price, JPL
Nuclear Weapon Radiation Effects	James P. Spratt
Introduction Technology Menu	Jack Hilibrand Gov't Systems Division RCA
Bulk CMOS for Space Systems	William R. Dawes Sandia National Laboratories
Radiation Hardened CMOS/SOS for Space Applications	Harold Borkan & George J. Brucker Advanced Technology Laboratories, RCA
Advances in Gallium Arsenide Integrated Circuit Technology	Allen Firstenberg Rockwell International
Impact of VHSIC Technology on Air Force Systems	John Blasingame AF Wright Aeronautical Laboratories
An Integrated Design and Manufacturing Approach to VLSI	Ralph Schauer IBM Corporation
High Density LSI Packaging with Hermetric Chip Carriers	John A. Bauer Missile & Surface Radar, RCA

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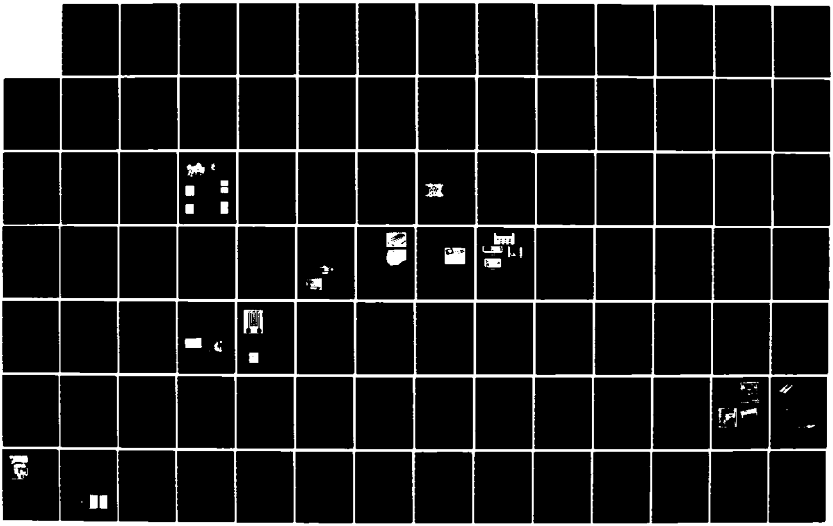

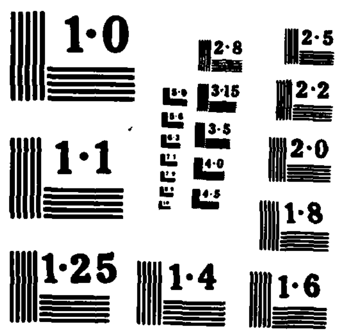
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Future Requirements for Microelectronics in Commercial Communications Satellites*

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Introduction

Commercial communications satellite systems have developed into an effective and reliable means of providing both global and domestic communications services. The growth and success of these systems have led to increased circuit capacities and satellite complexities.

In the past, commercial communications satellites have relied on dedicated hard-wired logic to provide the required monitoring, switching, and control functions. Since future generation communications satellites will have added complexity and require a significantly larger amount of such functions, the use of microprocessors and other LSI devices is necessary to provide added capability, flexibility, and reliability.

Commercial Communications Satellites

The world's first operational commercial communications satellite, INTELSAT I (Early Bird), was launched and placed in a geostationary orbit 35,780 km from the earth in 1965. It was capable of providing 240 two-way voice circuits between the United States and Europe. Since that time, approximately 110 satellites have been launched and placed in a geostationary orbit.[1] Approximately 40 of these satellites have been placed in commercial international or domestic communications service, and the remaining satellites have military, experimental, or meteorological communications functions.

Table 1 lists the commercial communications satellites currently in service. Of these, INTELSAT I, II, and III satellites have completed their mission and have been removed from orbit. The table also lists over 40 additional commercial communications satellites which are presently being designed and/or constructed and are expected to be launched during the next several years. In addition, more than 10 new series of commercial communications satellites are in the planning stage as of this date.

The majority of the commercial satellites included in Table 1 provide fixed satellite services such as telephone, telegraph, television, data and facsimile on an international, domestic, or regional basis. The oldest and largest satellite communications system includes the INTELSAT satellites which provide services on an international basis. Examples of domestic systems are the United States' Westar, Satcom and Comstar satellites, Canada's ANIK, Indonesia's Palapa, and the Soviet Union's Statsionar satellites.

The other commercial satellites shown provide mobile services. The COMSAT General Marisats provide combined UHF and L-band services to ships of many nations. Additional ship service will also be provided by the European Space Agency's Marecs satellites, and the Soviet Union is planning the use of Volna satellites for mobile services.

*This paper is based upon work performed at COMSAT Laboratories under the sponsorship of the Communications Satellite Corporation.

Table 1. Commercial Communications Satellites

Placed In Service

Satellite Series	First Launch	Number	Usage
INTELSAT I	1965	1	International
INTELSAT II	1967	3	International
INTELSAT III	1968	5	International
INTELSAT IV	1971	7	International
INTELSAT IV-A	1975	5	International
WESTAR	1974	3	U.S. Domestic
SATCOM	1975	2	U.S. Domestic
COMSTAR	1976	3	U.S. Domestic
MARISAT	1976	3	Maritime
ANIK A	1972	3	Canadian Domestic
ANIK B	1978	1	Canadian Domestic
PALAPA	1977	2	Indonesian Domestic
STATSIONAR	1975	2	U.S.S.R. Domestic

In Process

Satellite Series	Number Planned	Usage
INTELSAT V	8	International
WESTAR	1	U.S. Domestic
ADVANCED WESTAR	2	U.S. Domestic
SATCOM	1	U.S. Domestic
SBS	3	U.S. Domestic
ANIK C and D	4	Canadian Domestic
PALAPA	3	Indonesian Domestic
INSAT	2	Indian Domestic
ECS	1	European Regional
MARECS	2	European Maritime
CS	1	Japanese Domestic
STATSIONAR	6	U.S.S.R. Domestic
LOUTCH	7	U.S.S.R. Domestic
VOLNA	7	U.S.S.R. Domestic

Planned

Satellite Series	Usage
INTELSAT VI	International
ARABSAT	Arabian Regional
NORDSAT	Nordic Regional
AT&T	U.S. Domestic
BRASILSAT	Brazilian Domestic
SATCOL	Andean Regional
CHINASAT	Chinese Domestic
ITALSAT	Italian Domestic
AUSTRALIASAT	Australian Domestic
ESTEC	European Regional
HUGHES	U.S. Domestic
SOUTHERN PACIFIC	U.S. Domestic

A third class of commercial satellites that are not included in Table 1 are direct broadcast satellites. To date, only a few satellites of this type have been placed into service, and these have been primarily of an experimental nature. However, satellites of this type are in the planning stage, and such services will be provided in the near future by satellites developed by Japan, Germany, Canada, the Soviet Union, the European Space Agency, and COMSAT.

Satellite Complexity and Microelectronic Usage

The proliferation of communications satellites and increasing use of their services have resulted in additional complexity due to the need for greater circuit capacities and more commands, transponders, beams, and frequencies. One measure of design complexity is the number of individual electronic parts on a satellite. Table 2 (from Reference 2) shows the increased parts count and telephone circuit capacity for the INTELSAT series of satellites. Parts count has increased from 3,500 for INTELSAT I to 19,000 in the current operational INTELSAT IV and IV-A. Circuit capacity is 25 times as great per satellite. The INTELSAT V satellites, the first of which is planned to be launched and put into operation later this year, will have over 54,000 electronic parts and will double the present circuit capacity per satellite.

Domestic communications satellite complexities are also increasing. One of the currently operating U.S. domestic satellites, Satcom, has about 18,000 electronic parts. The Insat domestic satellite will have over 36,000 parts. Estimated part counts for some of the currently operating and planned satellites are shown in Table 3.

Table 2. INTELSAT Complexity

INTELSAT Satellites	No. in Orbit	No. Parts per Satellite[a]	No. Parts per Series	Transponders per Series	Circuit Capacity per Satellite	Circuit Capacity per Series
I	1	3,500	3,500	2	240	240
II	3	5,000	15,000	3	240	720
III	4	7,000	35,000	10	1,500	7,500
IV	7	17,000	49,000	84	4,000	28,000
IV-A	5	19,000	95,000	120	6,000	30,000
V	8[b]	54,000	432,000	216	12,000	96,000

[a]Excludes solar cells.
[b]Planned for launch.

Table 3. Satellite Microelectronic Usage

Satellite	No. Electronic Parts	No. Microcircuits
INTELSAT IV	17,000	1,700
INTELSAT IV-A	19,000	1,700
MARISAT	15,000	1,200
SATCOM	18,000	1.800
INTELSAT V	54,000	4,000
SBS	30,000	2,500
INSAT	36,000	3,000

Microelectronics usage has also been increasing as satellites become more complex. The first three INTELSAT satellites were relatively simple and made limited use of microelectronics. INTELSAT IV and IV-A used about 1700 microcircuits per satellite, primarily in the attitude control, telemetry and command systems. These were primarily low-power TTL SSI types. INTELSAT V will use about 4,000 microcircuits per satellite, with most items being TTL SSI and MSI types used in the attitude control and telemetry, tracking and command systems. In addition, there are over 400 custom hybrid circuits used in DC-to-DC converters throughout the satellite.

In most of the domestic satellites about 10 percent of the parts have been microcircuits, primarily digital SSI and MSI types in the attitude control and telemetry and command systems. Almost all were low-power TTL types except for the use of CMOS in Satcom. Several of the new satellites plan the use of large hybrid microcircuits and LSI microcircuits such as microprocessors, memories, and custom devices. Insat will use a bipolar microprocessor based attitude control system with 44 LSI microcircuits. SBS and ANIK C will use large hybrid microcircuits for power monitoring functions in their telemetry system. Advanced Westar plans to utilize LSI devices in attitude control and TDMA switching applications.

Future Microelectronic Applications

The continued growth and success of commercial communications satellites depends upon the use of new and improved techniques which will provide additional capacities and services, better performance, greater flexibility and control, and continued high reliability. The greater use of microelectronics can significantly contribute to these goals. However, the use of more of the same microelectronic devices that are in present-day operational satellites would provide an unattractive approach. The use of state-of-the-art devices including microprocessors and other LSI devices is necessary to provide additional capabilities without significantly increasing the number of parts required.

There are a number of spacecraft applications in which communications satellite performance could be improved by the use of state-of-the-art microelectronics. Many of these applications are part of present exploratory research and development programs and include attitude control, communications, and telemetry and command functions as shown in Table 4.

Table 4. Microelectronic Spacecraft Applications

Attitude Control	Skewed Reaction Wheel System
Communications	SS-TDMA Switching Regenerative Repeater Baseband Signal Processing Antenna Beam Reconfiguration
Telemetry and Command	Central Onboard Processor Telemetry Processor
Power	Battery Conditioning Power Management

A microprocessor based skewed reaction wheel attitude control system has been developed which provides greater accuracy, faster reaction time, and higher reliability.[3] It is capable of maintaining roll, pitch, and yaw accuracies of better than 0.05 degrees under all modes of operation. The control logic unit of the system uses an 8-bit bipolar microprocessor, a 4K PROM, and a 0.5K RAM and provides double precision arithmetic for attitude control, redundant operation of the reaction wheels, and telemetry and command inputs and outputs. Add time is about 7 μs and multiply time is about 9 μs. The predicted system reliability is 0.99 for seven years.

A number of communications system improvements are being developed to increase overall efficiency and capacity. These improvements include the use of complex multibeam antennas, satellite switching of time-division multiple-access (TDMA) beams at microwave frequencies, regenerative repeaters, and baseband signal processing. The use of state-of-the-art microelectronics will be a key element in the uti tion of the last three techn s.

Most present-day operational communications satellites employ frequency modulation and frequency-division multiple-access (FDMA) techniques for communications transmission. In TDMA systems, a given channel is shared by synchronizing a number of digital transmissions so that they appear sequentially at the input; this was first introduced operationally in the ANIK system in 1975. Almost all future communications satellites will utilize TDMA techniques to more efficiently use bandwidth and power. Satellite-switched TDMA (SS-TDMA) is a rapid, dynamic method of changing the interconnections between different up-link and down-link beams to provide additional flexibility which further improves efficiency.

An onboard switching center, which has been developed to provide SS-TDMA, contains a microwave switch matrix (MSM) and a programmable distribution control unit (DCU).[4] The MSM can be built using pin diodes or FET transistors for small matrices and will require microwave monolithic integrated circuits (MMIC) for large matrices. The DCU can include custom LSI circuitry, microprocessors, and LSI memories. It includes a telemetry and control interface which operates at slow speeds (1 kHz) and control electronics which operate at the high speeds (6 μs) required to switch the matrix elements.

The use of regenerative repeaters is being explored to improve satellite transmission strength and reduce power requirements in earth stations. Reference 5 describes the potential use of this technique. The transponder demodulates the up-link signal to baseband and provides onboard switching, reformatting, retiming,

and remodulation before transmitting the signal to the down-link.

Demodulating and regenerating the up-link signal of the satellite decouples the up-link noise from the down-link and improves carrier-to-noise ratio and, therefore, effective signal strength. The system utilizes microwave integrated circuits for up-converters and down-converters and an intelligent onboard baseband processor.[6] This processor includes a custom LSI circuit or microprocessor for timing, switching, and control; and RAMs and ROMs to store the regenerated signals. The onboard baseband processor can also be used to provide message switching, multiplexing, network and link control, traffic assignment, buffer management, digital speech interpolation, and other functions now performed by computers at the earth stations.

The telemetry and command systems of communications satellites provide many housekeeping functions including command decoding, telemetry processing, power management, battery management, and thermal management. The present approach employs a separate component to provide each of the required monitoring or processing functions, uses redundancy to improve reliability, and provides control by commands from ground telemetry, tracking, and command computers. This could be performed by an onboard microprocessor based computer as described in Reference 7. It would include an LSI microprocessor and RAM and ROM memories. Another approach is a telemetry system which continuously samples, conditions, and encodes measurements of satellite status, attitude, and performance to provide control and fault isolation. This system, which would provide more flexibility and improved accuracy and reliability, would include custom LSI circuits,[8] microprocessor bit slices, PROMs, RAMs and custom hybrid circuits.

General Considerations

There are numerous applications in which state-of-the-art LSI microelectronics can improve and expand communications satellite use and capabilities. However, in the selection of devices for specific applications, several important factors should be considered including the speed, power, environmental, and reliability requirements.

Figure 1 indicates power and speed requirements for the spacecraft systems which contain the primary applications for microelectronics. Telemetry and command normally utilize the least power and require the slowest operation rate. Typically, the telemetry electronics operates at bit rates of 1000 bit/s and uses 15 to 20 W of power. Attitude control electronics usually require 25 to 30 W of power and operating speeds of about 25 kbit/s. The communications system applications utilize the largest amounts of power and require speeds of 10 to 500 Mbit/s for onboard signal processing, regenerative repeaters, and SS/TDMA. Slow-speed, low-power applications are best suited for CMOS types of microcircuits; bipolar types would be required for the high-speed, high-power applications based upon today's technology.

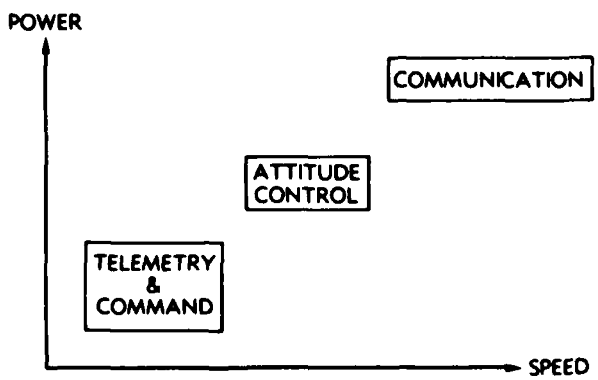

Figure 1. Power and Speed Requirements

The primary environmental consideration relative to the use of microelectronics is radiation sensitivity.[9] The radiation dose that accumulates during seven years in a geosynchronous orbit for silicon shielded by aluminum or lead is shown in Figure 2 (from Reference 10). The total radiation absorbed reaches a point beyond which it cannot be reduced by further shielding. This value is 3 x 10^4 rads for lead and 4 x 10^3 rads for aluminum. If the electronics are placed in the center of a satellite, the structure and other components provide approximately 4 to 5 mm of aluminum shielding, reducing the accumulated 7-yr dose on a microelectronic device to between 10^4 and 10^5 rads.

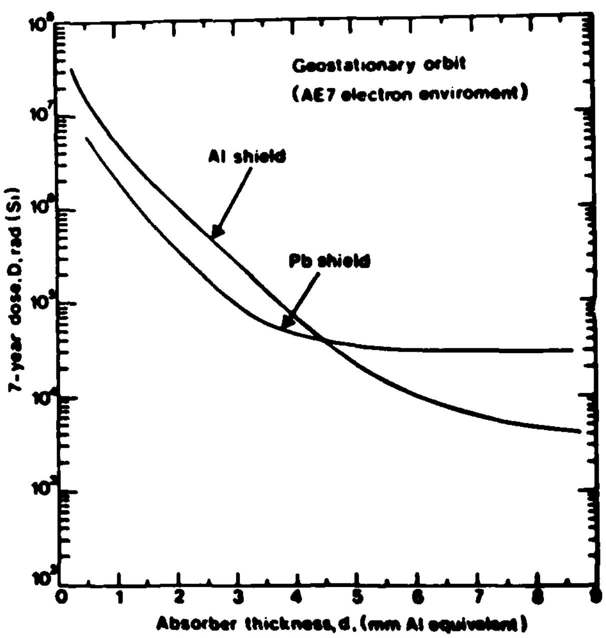

Figure 2. Dose-Depth Curve for Al and Pb in Geostationary Orbit

Figure 3 (also from Reference 10) shows the number of years required for a device with 4.5 mm of shielding to reach four different assumed fatal radiation doses. The increase in the number of years required is also shown for added thicknesses of aluminum shielding. A device with a radiation tolerance of 10^3 rads will not survive two years even with 10 mm of shielding. A device with 10^4 rads radiation tolerance requires about 6 mm of shielding to survive seven years. Most currently popular commercial NMOS microprocessors exhibit failure between 10^3 and 3 x 10^3 rads.[11] Various tests on CMOS devices have indicated a radiation tolerance of 10^4 to 10^5 rads, while bipolar devices have consistently demonstrated radiation tolerances of 10^6 rads or better.

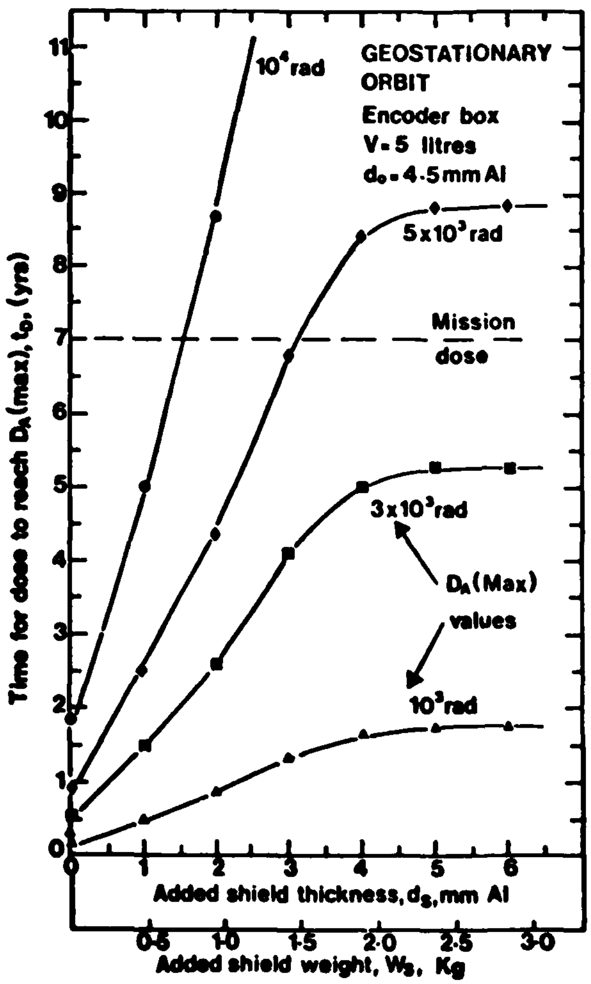

Figure 3. Survival of CMOS Circuits in a Particular Location of a Communications Satellite.

The performance of commercial communications satellites has been characterized by very high reliability. The continuity of service of the INTELSAT space segment has exceeded 0.99995 since 1970. This high reliability has been maintained by reliability programs incorporating key elements such as redundancy, the use of devices with suitable design lifetime, and the elimination of potentially defective electronic parts through testing, screening, and burn-in.

This high reliability has continued even though satellite complexity has increased. This has been due, in part, to the use of SSI and MSI microelectronic devices. These microcircuits allow the integration of a number of discrete parts, and therefore, more functions were included without a corresponding increase in parts. In the future, this trend can be continued by using LSI devices. In fact, additional reliability improvement should be possible due to a smaller number of physical parts per function, the elimination of interconnections, and the availability of added flexibility for redundancy.

The traditional method of designing spacecraft has been to build components for particular tasks and to redundantly cross couple multiple components in parallel to improve reliability. By replacing certain components with general purpose microprocessor modules, this same method of redundancy can be continued. In addition, these microprocessor modules can perform numerous tasks, and any task can be shared between a number of microprocessor modules. By grouping the microprocessors, each microprocessor could then perform its own task, as well as be able to take over other tasks. Therefore, reliability would be further improved.

The design lifetime of LSI microelectronic devices should not normally significantly affect satellite reliability. The normal degradation of a typical semiconductor device is such that a mean-time-to-failure of at least one million hours, or greater than one hundred years, can be predicted. Even though an LSI device contains a large number of semiconductor junctions, the mean-time-to-failure should still be much greater than required. The only factor that could limit the design lifetime is failure due to low radiation tolerance.

Reliability programs for long-life commercial satellites have included screening programs to eliminate potentially defective electronic parts. Parts programs have required qualification, control, and derating of all electronic parts. Typical INTELSAT part screening procedures have included burn-in of all active electronic parts for 672 hr with a minimum of four data points which are analyzed for parameter drift. These reliability procedures should be applied to LSI devices used in future satellites. In addition, lot radiation qualification may be required. Also, since the devices are more complex in both function and design, adequate functional testing must be developed and utilized. In addition to AC and DC parametric testing, test programs must be developed to verify that as many faults as possible have been identified.

Future satellite microelectronic applications will utilize standard microprocessor and LSI devices and custom LSI devices. Standard microprocessors are general purpose devices that can be used to digitally process most tasks. Custom LSI devices are special purpose units which can be designed to perform digital tasks similar to those of a microprocessor or analog or a mixture of analog and digital functions. Both types of devices have potential applications in satellites. Al-

though, in some cases, either can be used, in terms of reliability, the "standard" microprocessor is preferable. First of all, the microprocessor is a general purpose device and can provide added redundancy for multiple tasks as previously discussed. In addition, the complexity of the LSI device increases the difficulty of testing. The probability of developing a test program to find and correct design errors depends on the number of devices tested. Microprocessors are produced in volume for various applications. Satellite applications for special purpose custom LSI chips will normally require a small number of devices, and, therefore, test programs for such devices will not be as effective. Finally, it is difficult to obtain high-quality manufacturers who will produce low-volume custom LSI devices. Those who will produce such devices normally use MOS techniques which presently have a low radiation tolerance. Bipolar and possibly CMOS standard microprocessors are available which have a higher radiation tolerance.

Conclusions

The use of state-of-the-art LSI microelectronic devices is required in future commercial communications satellite applications to fulfill the need for added complexity while maintaining high reliability. Both standard microprocessor and LSI devices and custom LSI chips can be used, but microprocessors are preferred if a choice is possible. Important considerations in the selection and application of LSI devices include speed and power requirements, radiation tolerance, and reliability factors such as redundancy, testability, availability, and capability.

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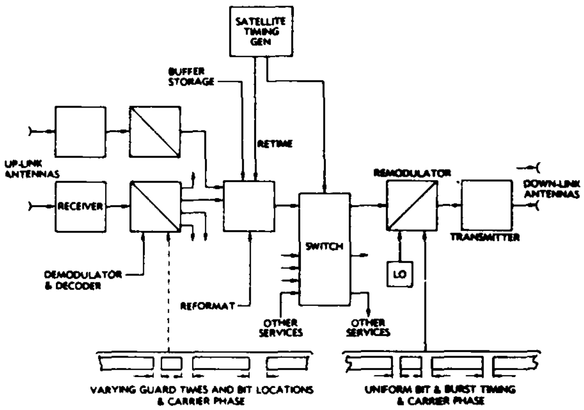

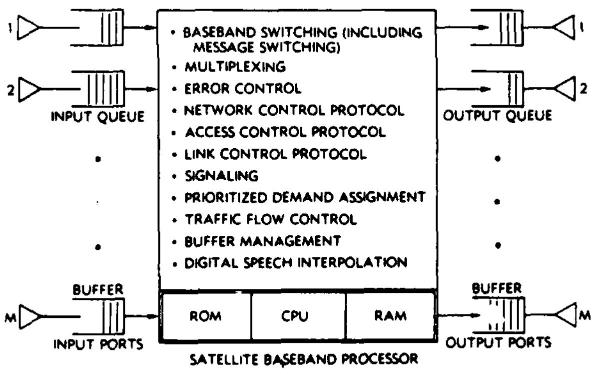

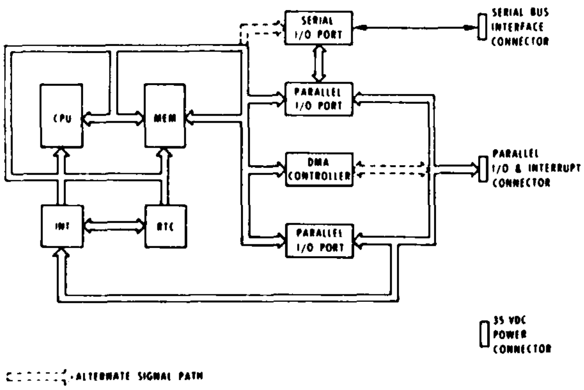

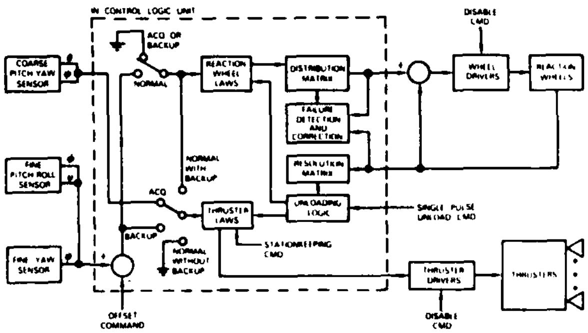

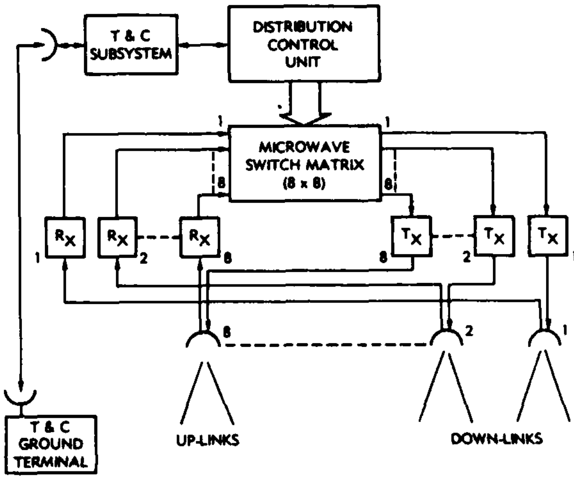

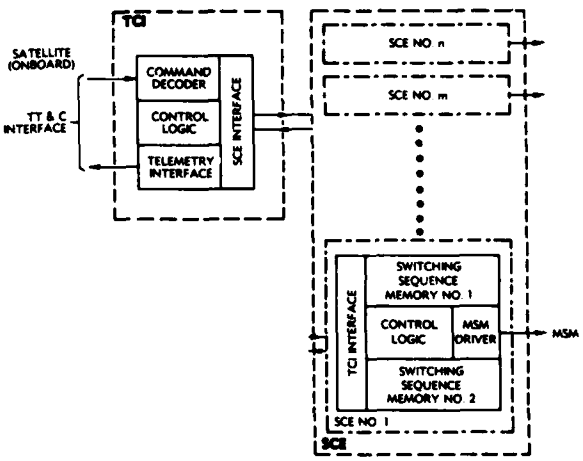

CLASS S LSI REQUIREMENTS, CURRENT STATUS, AND PROJECTIONS FOR THE FUTURE

by

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SUMMARY

Class S requirements for LSI circuits are currently in a very preliminary stage. Existing LSI specifications, and associated quality control procedures and test methods, are essentially an extension of those employed for SSI and MSI and do not reflect the significant differences encountered when dealing with LSI. For example, many screening techniques such as precap visual inspection, electrical test or burn-in which were relied upon heavily in the past to achieve reliable integrated circuits cannot be as effectively applied to LSI. Proposed MIL-STD-1547 contains sections specifically covering LSI; however, these are largely undeveloped. In recognition of the new procurement and testing problems presented by LSI, the Air Force Space Division's Space Parts Working Group has formed a special LSI committee to study and make recommendations in the areas of General Requirements, Certification and Qualification, Testing and Characterization, and Radiation Hardness for Class S LSI circuits. Major problems which are currently inhibiting the growth of LSI applications in Space Division programs include radiation hardness, adequate reliability testing and the high cost associated with the development and manufacture of small quantities of special circuits. In order to effectively achieve Class S LSI for future programs, it will be necessary to:

1) Develop realistic and consistent performance and radiation requirements.
2) Establish qualified, radiation hard LSI technologies.
3) Establish qualified, standard computer aided design systems for custom LSI circuits.
4) Establish, radiation hard standard LSI circuits.
5) Evolve a more appropriate set of product assurance requirements and test methods.

CONCLUSIONS

- Existing Class S microcircuit requirements are inadequate for LSI.
- Custom LSI circuits will offer significant advantages to future Space Division projects.
- Radiation and performance requirements limit the use of LSI technology.
- Standard LSI building blocks will be essential to all systems.
- LSI testability is the major reliability problem.

RECOMMENDATIONS

- Develop a set of product assurance requirements and test methods which are effective for LSI.
- Develop qualified standardized computer aided LSI design systems and associated radiation hard LSI technologies.
- Establish realistic and consistent radiation and performance requirements.
- Establish a qualified radiation hard set of LSI building blocks.
- Implement design for testability requirements in all future custom LSIC's.

Status of Class S LSI Requirements

- o No essential differences from SSI/MSI defined as yet.
- o Proposed MIL-STD-1547 contains LSI sections which are very preliminary.
- o USAF/SD Space Parts Working Group has formed a committee to make recommendations.
- o Existing requirements for Class S microcircuits not adequate for LSI.

Problems with Applying SSI/MSI Requirements to LSI

- o Characterization typically incomplete.
- o Exhaustive functional testing not feasible.
- o Device characteristics not measurable.
- o Visual chip inspection ineffective.
- o Operating burn-in not readily implementable.
- o Fault location (failure analysis) very costly.
- o Special in-process controls more difficult to institute.

Major Obstacles to Class S LSI

- o Testing, Functional and Device.
- o Failure experience.
- o Radiation Hardness.
- o Special, low volume requirements.

Solutions to LSI Testing Problem

- o Thorough characterization of standard LSI functional building blocks.
- o Incorporation of reliability test chips on LSI wafers.
- o Design for testability on custom LSI circuits.
- o Sharing of LSI test programs and results among Class S users.

Solutions to LSI Radiation Problem

- o Establish realistic and consistent radiation requirements.
- o Consider maximum effective use of system design and shielding alternatives.
- o Establish qualified, standard radiation hard technologies.

Solutions to the LSI Reliability Problem

- o Establish qualified, standard functional building blocks.
- o Establish qualified, standard computer aided design systems and design centers.
- o Establish qualified, standard LSI technologies and manufacturing facilities.
- o Develop LSI specific quality control methods.
- o Share LSI reliability test and failure experience data among Class S users.

Concluding Observations

- o Class S LSI will be largely "custom" due to testability, radiation hardness, and quality control requirements.
- o Considerable "up-front" effort will be required to establish standard, qualified building blocks, CAD systems, and radiation hard technologies.
- o A much more intensive and coordinated research and development effort is required to meet the needs of the space community.

SPACE RADIATION EFFECTS AND COSMIC RAY INDUCED UPSETS IN MODERN SEMICONDUCTOR DEVICES*

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INTRODUCTION

Electronic systems in spacecraft and satellites can be hardened against space radiation effects. The hardening effort must be started early in the system design to keep costs within acceptable limits. System hardening is mostly a parts selection problem interwoven with proper circuit design backed by shielding analysis and application for space radiation situations.

Space radiation consists mostly of charged particles and some electromagnetic secondary radiation. The particles have a vast range of energies, most of which are not highly penetrating. Therefore, the intrinsic mass of the spacecraft has value as shielding as well as the materials which have been added specifically for such purposes. The surface materials of a spacecraft receive much higher doses than the interior of the spacecraft. However, the semiconductor devices are orders of magnitude more sensitive than any material or other types of devices. So the system hardening problem resolves into a program of semiconductor device selection and circuit design to accommodate the radiation effects as determined by radiation tests.

Another space radiation type of concern is cosmic rays which can induce single event upsets in memory devices. This problem has only come into view since 1975 but as device geometries get smaller this problem gets larger. Other radiation types will not be considered here, although it is well known that gamma rays and neutrons from nuclear weapons are highly penetrating and can not be readily shielded. Also, the rate of irradiation can be an important factor for nuclear weapon environment. However, the rate of irradiation for most space radiation is low enough so that there is no problem to electronic systems.

SELECTION OF SEMICONDUCTOR DEVICES

System hardening by device selection depends to some extent on the radiation dose level specified for the mission. Levels of 5000 rad(Si) or under are relatively less difficult than the dose levels for spacecraft such as Voyager and Galileo which must survive the severe radiation fields at Jupiter and have specification levels of 150 Kilorads(Si). However, the approach to hardening is similar.

The philosophy in the approach to selection of devices is the result of several technical facts which are somewhat related to the details of the radiation environment and mission parameters. It is important to keep in mind that space radiation produces two major effects in semiconductor devices; surface ionization effects and bulk damage. The surface effects are the most important because they are the most prevalent effect. The bulk damage effects become important only for high energy particles and in devices which have a large base such as low frequency pnp transistors (f_{ab} <100 MHz) and power devices.

The radiation induced surface effects are directly related to the physical conditions of the device surfaces and the oxide layers which are directly related to the details of the manufacturing processes and especially the

*This paper presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under Contract No. NAS7-100, sponsored by the National Aeronautics and Space Administration.

high temperature steps. Selection of devices for total dose hardened systems is dependent on characterizing devices with radiation tests which represent a process line and a particular manufacturer. This means that radiation effects determined for one device type and one manufacturer is not valid for all manufacturers of that type. For example, it has been found that there may be as much as three orders of magnitude difference in sensitivity between two manufacturers of the 2N2222 transistors.

In addition to this problem it also has been shown that there exist serious differences between diffusion lots and between wafers in the same diffusion lot. These differences occur because of process step differences uncontrolled in manufacture. Radiation induced surface ionization effects cannot be predicted by any pre-irradiation electrical or physical measurements. As a result, all devices must be radiation tested during the design phase of the system or else relatively recent test data must be found which characterizes the desired electrical parameters at the specification radiation levels. It is useful to have data both above and below the specified dose level to allow a determination of the safety margin and the requirements, if any, for shielding the part. A method for doing total dose radiation tests has been developed (see Ref. 5).

After devices have been found adequate and designed into the system there is a production phase in which one or more of the systems are built. The production may occur soon after the design or years later. Hardness assurance practices require radiation testing of a sample from each lot of semiconductor parts purchased unless it can be shown that there is an adequate safety factor which precludes testing. It has been common to find that when a long period has passed (after the radiation test data was obtained and used in design) until the production, that the data base can slip and may even impact design. For this reason it is prudent to use a sufficeint safety margin during design.

The Galileo spacecraft uses a safety margin of two for engineering subsystems. This spacecraft is being engineered at the Jet Propulsion Laboratory to be launched in 1985. It will orbit Jupiter a number of times. Table 1 shows the transistors which were radiation tested for use on the spacecraft. The third column shows which of the device types had hardness assurance requirements. Comparison of column 2 and 3 shows the rejection rate. Table 2 shows a similar array of information for integrated circuits such as operational amplifiers, comparators, and others.

Table 3 shows all LSI devices tested. None of the LSI devices were subjected to HA accept/reject criteria. In fact, while all of the LSI devices were tested to find out if they were useful for Galileo, most were found to be too sensitive for consideration. The AD571 is an exception as well as the 1800 series parts. These are presently being considered for Galileo. It is well established that the trend toward smaller geometry and larger complexity in LSI type devices results in greater radiation sensitivity. Complex LSI devices are failing at dose levels between 1 and 75 Kilorads (Si). For more details on radiation hardening of systems for space applications see References 1 through 4. A guideline document is being prepared concerned with methods used for obtaining hardness assured devices (See Ref. 6). A flow diagram, Figure 1, from that document gives a design and hardness assurance plan for hardening systems.

Single Event Upsets from Cosmic Rays

A relatively new phenomenon has come to notice in recent years which can, and has, caused problems with operational space systems. Cosmic ray particles have been shown to induce soft errors in memory systems and in information handling systems.

A series of laboratory tests carried out within the last year have outlined the problem to an extent not possible by theoretical analysis alone. Previously analyses of

specific device types had determined that devices (being used in operational space vehicles) could be upset by ions in the mass region of iron. These ions are plentiful in the cosmic ray spectrum. The laboratory tests have confirmed the theoretical analyses and have gone a step or two further. A fair array of device types already in space or planned for use in space vehicles were exposed to 150 MeV Argon and Krypton ions. The specific ionization of these ions bracket that of Iron.

What the experiments have shown is that the memory devices in common use have a wide range of susceptibility to cosmic ray induced upset. Dynamic RAM's are particularly susceptible because the capacitance of the sensitive node gets quite low during refresh cycles. Certain CMOS memories have been shown to have a low sensitivity to upset. These include memory device types used in the Voyager spacecraft and in the Galileo spacecraft.

Tests of dynamic devices with 50 MeV protons and 14 MeV neutrons have shown them to be upset. However, a similar test of a large number of static memory devices showed no upset. The mechanism for upset with neutron and protons is the production of alpha particles within the memory cell by nuclear reactions. Modeling of the sensitive regions of memory devices can help predict whether a particular device will be susceptible, but there are some unknown quantities which must be assumed or estimated. Also, critical information is often difficult and time consuming to obtain from the manufacturer, making predictions less sure. Ultimately it is still necessary to carry out a test to assure the validity of the model. So that it is recommended that tests be carried on all devices which are to be considered for use on spacecraft. As newer device types become available there is a tendency for the cell sizes to be smaller. This will likely cause greater susceptibility to single event upsets. The problem is bound to become greater for future applications using the more sophisticated new device type. Error correction systems will be needed to compensate. References 5 through 13 give a full treatment of the single event upset problem as induced by space radiations. In addition, reference 13 gives a view of the expect rate of upsets from cosmic ray showers for earth bound systems.

Conclusions and Recommendations

1. An array of discrete semiconductor devices can be procured which are suitable for use in a radiation hardened system. It is recommended that for Hardness Assurance, marginal devices should be lot sample tested.

2. Large Scale Integration (LSI devices are radiation soft; 1 to 25 Kilorad (Si). Radiation hardened systems may not be able to use such devices without special hardening efforts, i.e., shielding or redesign.

3. Single event upsets in memory devices induced by cosmic rays, and other heavily ionizing events can be a problem to spacecraft and earth bound systems. It will be a continually worsening problem for the future where device geometries become ever more upset sensitive due to their decreasing size. It is recommended that all memory devices be tested to confirm their upset susceptibility.

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TABLE 1

DISCRETE SEMICONDUCTOR DEVICES RADIATION
TESTED FOR THE GALILEO SPACECRAFT PROGRAM

DEVICE NO.	NO.OF LOTS TESTED	NO.OF LOTS REJECTED	DEVICE NO.	NO.OF LOTS TESTED	NO.OF LOTS REJECTED
C11D	4	0	2N3251	4	3
MQ2905	2	1	2N3331	1	0
SDT3303	2	0	2N3350	6	2
SD3304	5	1	2N3391	1	0
SD3323	5	3	2N3467	2	0
SDT5553	1	0	2N3501	1	0
2N918	1	0	2N3637	1	0
2N2060	2	0	2N3700	7	1
2N2222	14	5	2N3799	2	0
2N2369	1	0	2N3805	5	N/A
2N2484	1	N/A	2N3821	1	N/A
2N2608	1	N/A	2N3824	1	N/A
2N2658	2	1	2N4044	2	1
2N2880	2	0	2N4260	1	N/A
2N2905	3	1	2N4856	1	0
2N2907	15	9	2N5087	1	N/A
2N2920	8	5	2N5196	5	3
2N2975	4	N/A	2N5556	2	N/A
2N3032	1	N/A	2N5663	1	0
			2N6138	1	0
			96SV131	3	0
			14BB101	1	N/A

TABLE 2

INTEGRATED CIRCUITS RADIATION TESTED
FOR THE GALILEO SPACECRAFT PROGRAM

DEVICE NO.	NO. OF LOTS TESTED	NO.OF LOTS REJECTED	DEVICE NO.	NO. OF LOTS TESTED	NO. OF LOTS REJECTED
CD4001	1	N/A	HA2-2520	2	N/A
CD4011	1	N/A	HA2700	1	N/A
CD4013	3	N/A	H1-2-200	2	N/A
CD4014	1	N/A	H1-1800A-2	2	N/A
CD4027	2	N/A	LF155	1	N/A
CD4049	2	N/A	LF156	2	N/A
CD4052	2	N/A	LM101	18	N/A
CD4053	2	N/A	LM106	1	N/A
CD4066	1	N/A	LM108	40	0
CD4099	2	N/A	LM111	47	20
CD40115D	1	N/A	LM119	20	4
DG141	1	N/A	LM139	19	8
HA1-2420	2	N/A	LM158	1	N/A
HA2-2050-2	1	N/A	4720DM	1	N/A

TABLE 3

LSI DEVICES RADIATION TESTED FOR THE
GALILEO SPACECRAFT PROGRAM

DEVICE NO	NO. OF LOTS TESTED	DEVICE NO.	NO. OF LOTS TESTED
AD571	6	MM54C905	1
AD574	3	MM54C920D	1
AD7521	1	MM54C929	2
ADC1210	2	MM70C95	1
CCD800X800	1	MN371	1
CDP1802	1	MN5216H	1
CDP1834	2	MN9181	1
CDP1852	1	MP7570	2
CDP1856	3	MWS5001D	1
DAC-08	3	MWS5501	1
HM16611-9	1	SBP9900X	1
HM6508	2	SMP11	1
HM9-6551B-9	1	TCC244	1
IM6508MDE	3	TDC1001-J	1
MB5101L-4	1	TDC1021-J	1
MCM418M	1	XR215	1
MM251	1	54C200	1

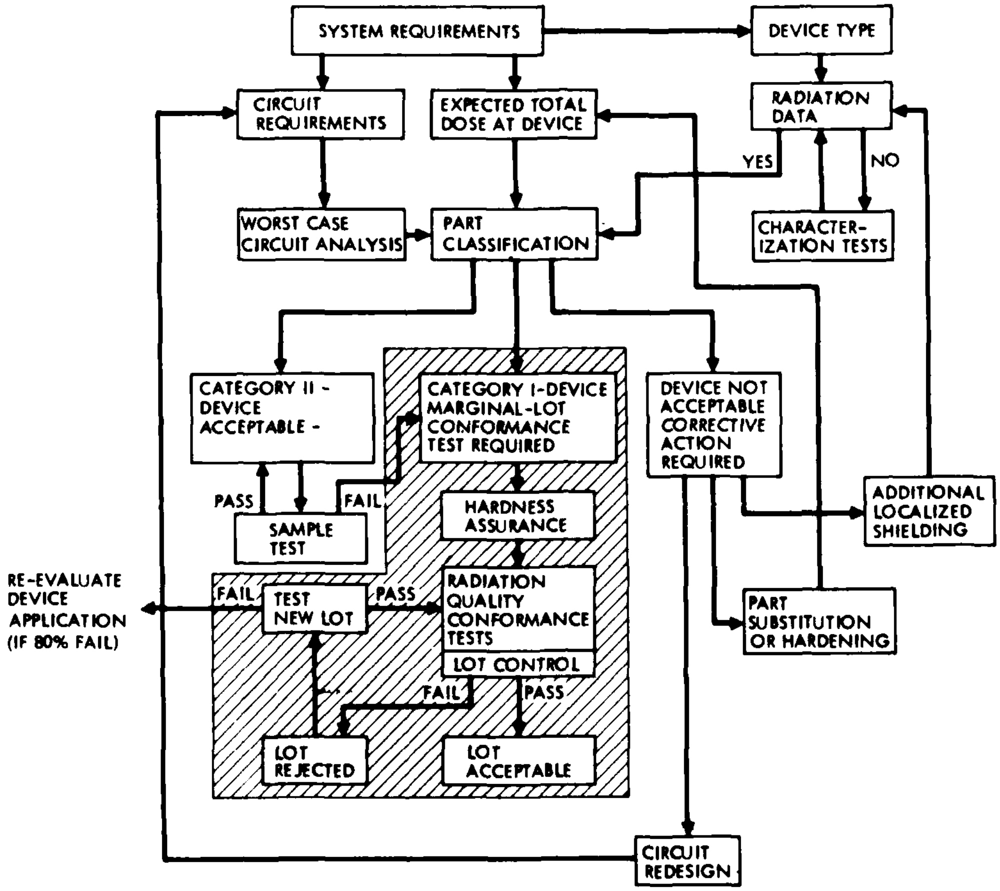

Figure 1. System Total-Dose Design and Hardness Assurance (HA) Plan (HA function in shaded area).

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Micorelectronic Requirements for Future Space Missions Nuclear Weapon Radiation Effects

1.0 Introduction

Five years ago, the radiation effects community was very confident that LSI could be hardened to levels demanded by strategic weapon systems and military satellite systems. The Lockheed C-4 parts program was well underway at that time, and it was expected that the parts family being developed thereunder would represent the last example of military user being many years behind the commercial world. Two major process technologies were being developed for hard LSI applications (viz. CMOS/SOS and I^2L), and both were judged capable of replacing and surpassing dielectrically isolated LSTTL. Today, the only parts available for use in systems which must be hardened at strategic levels to nuclear weapons effects are the C-4 parts or their derivatives developed under the MX program. Instead of being five years behind the commercial world, we are ten years behind and expect to see the lag increase for some time. It is time to reconsider our strategy for the development of radiation hardened LSI. This paper makes some suggestions for a new strategy for attacking this problem.

2.0 Statement of Problem

2.1 Impact of Nuclear Weapon Effects on LSI Technology Selection

Contrary to popular opinion, neutron damage effects rarely limit the application of LSI technologies to strategic missile systems and never limit in the case of military space systems. Total ionizing radiation dose and dose rate are the elements of the environment which determine what can and can not be used. To date, the radiation effects community has started the search for suitable technologies with the assumption that the inherent susceptibility of junction isolated (JI) IC processes to transient ionizing radiation dictated the use of dielectrically isolated (DI) processes. Specific DI processes which have been exploited include the single crystal bucket approach (for bipolar) and silicon-on-sapphire (for MOS). Neither of these could be described as a consensus selection for use in LSI, but they are free of radiation induced latchup, and resistant to burnout or logic upset in transient ionizing radiation. Consequently they have received major attention for hardened LSI.

2.2 Current Status of Dielectrically Isolated Integrated Circuit Development

Bipolar DI integrated circuits are presently at a level of integration corresponding to SSI/MSI. Figure 1 lists the types of digital functions one can find available in this technology. It is questionable how much further one can go in level of integration with such an approach. MOS integrated circuits, on the other hand, never really attempted to develop through the SSI/MSI route. CMOS/SOS technologists jumped directly to LSI in their attempts to produce hardened integrated circuits. Differences of opinion exist as to where the technology actually stands today, but it is safe to that no major strategic or space systems plan to procure radiation hardened CMOS/SOS LSI for use in flight hardware for at least two years. Progress made in this area has not been up to the expectations of those working in the field.

3.0 Possible Alternate Approaches

Many weapons and reconnaissance systems to be deployed during the 1980's require LSI to perform their functions properly. If, as appears to be the case, it will not be possible to procure DI devices for this purpose in the time frame of interest, we must re-examine the utility of what we can procure. Bipolar bit-slice processors, memories, and gate arrays are available in militarized versions of commercial devices fabricated in junction isolated technology. Similarly, there is good evidence that a useful range of CMOS devices on bulk silicon could be made available with some additional development work (Cf. Bill Dawe's discussion in this workshop). If system level approaches are taken to transient ionizing radiation har-

dening, either or both of these technologies could provide LSI useful for military system application. Requirements which these system hardening approaches must satisfy can now be discussed.

3.1 Requirements for System Level Hardening of LSI Systems

Junction isolated IC's respond to transient ionizing radiation by passing large photocurrents. Photocurrent can cause destructive burnout of chips, logic upset, or latchup. To harden systems against these failure modes, it is necessary to limit the current which a chip can draw from the supply during the prompt pulse, to protect critical variables, and to power manage to delatch susceptible circuits. Each of these requirements imposes additional system overhead.

3.1.1 Current Limiting

To provide adequate current limiting, off-chip resistors are required. For systems employing SSI/MSI, this might impose a large overhead in power, weight, and volume. With LSI, however, this penalty is proportionally less because fewer IC's are needed to accomplish the required logic functions.

3.1.2 System Circumvention and Recovery

It is standard practice to store critical variables in hardened military systems in non-volatile memory to prevent data loss during radiation events. Plated wire has been the preferred memory technology, but the high cost of this approach, and architectural difficulties which discourage distributed memories, make it probable that this will be replaced in the near future by nonvolatile semiconductor memory (MNOS). If such developments do occur, a major milestone in system level hardening to transient radiation will have been achieved.

3.1.3 Latchup

Radiation induced latchup can cause destructive damage to a chip. If external current limiting prevents such damage, the latchup condition, at the very least, precludes normal operation. To restore system operation, chip power must be interrupted. This can be done periodically (strobing) or on demand (crowbarring). The technique has been used on memory systems, and should be extendable to complete LSI systems.

4.0 Summary and Conclusions

Development of dielectrically isolated LSI hardened to nuclear weapon radiation effects has proven to be much more difficult than was anticipated five years ago. In view of the problems encountered, the overall approach to LSI development for stragetic and military space applications must be re-examined. Our previous pre-occupation with transient hardness restricted studies to DI approaches to the exclusion of JI approaches. Several JI technologies, however, are adequately hard to neutron fluence and total ionizing radiation dose. To take advantage of the hardness of these JI technologies, system level approaches to transient radiation effects must be developed.

CIRCUIT FUNCTIONS PRESENTLY AVAILABLE IN DIGITAL BIPOLAR DIELECTRICALLY ISOLATED INTEGRATED CIRCUITS:

- QUAD 2 NAND
- DUAL 4 NAND
- FLIP-FLOP
- MUX
- DEMUX
- REGISTER FILE (4X4)
- ALU (4 BIT)
- ROM (1024 BIT)
- COUNTER
- SHIFT REGISTER

THE TECHNOLOGY MENU

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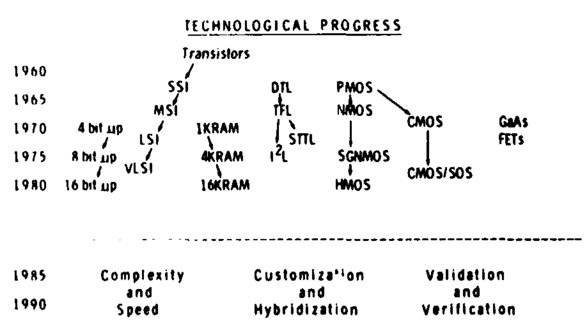
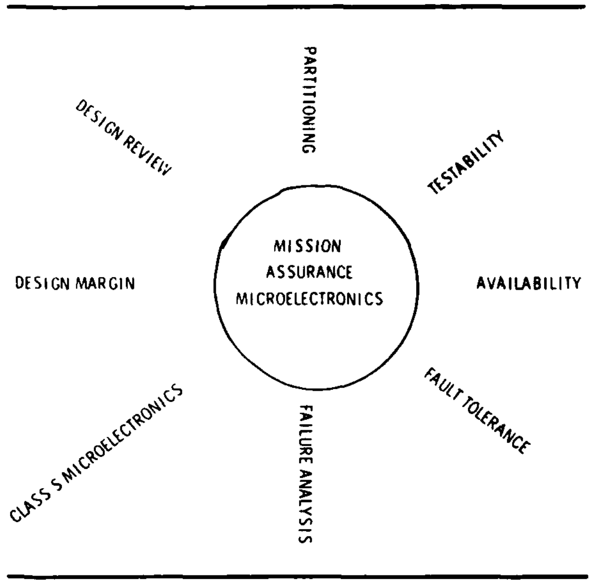
This is a time of revolutionary change in microelectronics. We are in transition from SSI/MSI logic to programmable subsystems, from catalog parts to custom arrays, from LSI to VLSI/VHSI complexity, and from human-dominated design and test activities to those same activities dominated by computer support aids. It is important to tread the narrow line between eschewing all new technology on the basis that it is untried and the eager pursuit of each new capability as it appears. This session is intended to first identify several of the more promising new technologies for space missions so that you can evaluate their potential and then to identify some of the validation and verification tools that are used to prove-in these new technologies. Advanced space missions are critically dependent on using new technology to the maximum possible extent, just short of introducing reliability hazards. Today's quick scan of the technology menu should both whet your appetite for the new technologies and provide some caveat emptor warnings against letting your appetites overwhelm your good judgment.





BULK CMOS FOR SPACE SYSTEMS*

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Introduction

Microelectronic systems for space use typically have component requirements that are characterized by low volume, high reliability, and severe environmental conditions such as ionizing radiation. Silicon gate CMOS technology has applications in space systems because of its low static power dissipation, high performance, good noise margin, and relative insensitivity to threshold voltage shifts. This paper will review a radiation hardened bulk CMOS silicon gate technology that has demonstrated megarad hardness, latch-up immunity, and high reliability. This process has been used to fabricate and deliver high-reliability, flight-quality parts of both a microprocessor family and custom logic circuits. A CMOS radiation-hardened standard cell design package is being developed to permit in-house design, prototype fabrication, design verification, and second source capability for government systems.

The nature of the rapidly expanding commercial market with its emphasis on high volume, and by space standards, modest environmental and reliability constraints, has increased the difficulty in obtaining qualified parts for many space systems. Future successful circuit procurement will require not only that the device technology is capable of meeting the specialized space requirements but also that guaranteed access to the design exists for independent circuit verification and multiple source capability. This paper will discuss a radiation-hardened bulk CMOS technology and a design implementation that has been successfully applied to procure radiation-hardened CMOS LSI parts for satellite systems.

Discussion

Space systems generally require circuits that demonstrate high reliability, since there may be 10-year system life requirements, static power dissipation on the order of 1 mW per LSI chip, some degree of radiation hardness, and finally, a guaranteed source. The radiation levels vary for different systems, but for the purposes of this paper, the radiation environment is 1×10^{14} n/cm^2, a total ionizing dose of 5×10^5 rads (Si) and transient survivability, i.e., no latch-up at any $\dot{\gamma}$ level.

This paper will discuss only the silicon gate technology, since it offers appreciable performance and packing density advantages over the metal gate technology and moreover has become the industry standard.

The radiation hardening for a bulk CMOS process is a three-step procedure. The gate oxide region for the active devices is first hardened to ionizing radiation and then the parasitic n-channel field oxide devices are hardened to prevent field inversion. This field oxide is hardened either by guardbands, a closed geometry layout, field shields, or more recently, a hardened field oxide. The final hardening consideration is to prevent latch-up which can be initiated by a transient ionizing radiation exposure. MOS structures are inherently hard to neutrons.

The radiation-hardened process for silicon gate circuits has been previously documented[1] and basically utilizes a 550 Å gate oxide grown at 1000°C with 100 percent O_2 and minimized postgate thermal cycles. To minimize the postgate thermal cycles, the n+ and p+ regions are formed by ion implantation, and a 950°C CVD oxide is used for the interlevel dielectric. The step coverage of this oxide satisfies step coverage requirements without the necessity of a reflow cycle, and concommitantly activates the ion implantation.

Hardening the parasitic n-channel field oxide device is presently done by layout techniques. For example, a closed geometry technology such as C^{2}L surrounds all drains with the gate electrode, thus there are no parasitic field oxide paths between drains.[2] Other techniques such as diffused guardbands, which in a silicon gate process require an additional photodelineation and diffusion, or field shields have demonstrated their effectiveness at preventing field inversion

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at the slight expense (typically 10 percent) of packing density.[3] From a packing density viewpoint, the optimum field oxide hardening approach from those discussed is a combination of diffused guardbands and field shields. A layout technique utilizing such a combination will be reviewed later.

The final hardening consideration for a bulk CMOS technology is the prevention of latch-up induced by an ionizing radiation transient spike which can exceed 1×10^{12} rads/sec. Again, several generic process solutions have been developed to prevent latch-up. These include minority carrier lifetime control such as neutron irradiation or gold doping, which maintains the parasitic npn and pnp beta product to less than unity.[4] This technique is well established and is universally successful for CMOS structures utilizing 4 μm design rules with p-well depths ≥ 5 μm. For designs with tighter design rules, the neutron exposure required to prevent latch-up exceeds 1×10^{14} n/cm^2 due to the narrow parasitic base widths and thus becomes unattractive. An alternative approach, which does not require a neutron source and is applicable for tighter design rules, is to use an n on n+ epitaxial substrate which provides a shunting path in the parasitic SCR, thus preventing latch-up.[5,6] Table I illustrates the data base for latch-up prevention of bulk CMOS for a variety of circuits and design rules.

Table I
Bulk CMOS Latch-Up

Lifetime Control
Sample size: >13,000 packaged parts
> 6,000 die (prepackaged)
Latch-up Test: 10^7-10^{10} rads/sec (Febetron)
10^{11}-10^{12} rads/sec (Hermes)
electrical

Epitaxial Substrates
Sample size: 12 wafer lots
>300 packaged parts
Latch-up Test: 10^7-10^{10} rads/sec (Febetron)
10^{11}-10^{12} rads/sec (Hermes)
electrical

Our first application of the hardened silicon gate bulk CMOS process was to the RCA designed 1802 microprocessor family, in particular, the 1802 microprocessor, the TCC-244 (256 x 4) RAM, and 1834 ROM. These circuits utilize a C^{2}L layout which eliminates radiation induced field inversion, thus modifying the process to radiation harden the gate oxide and to prevent latch-up would satisfy the radiation specifications. The gate oxide hardening was accomplished by using the previously mentioned oxidation-post oxidation sequence and a 1×10^{14} n/cm^2 radiation to control minority carrier lifetime and prevent latch-up. The radiation characteristics of the RAM are listed in Table II for 10 volt operation. The data represents the range for five device lots, and all exposures were at a 2×10^6 rad/hour rate with the part at a 10 volt static bias.

Table II
TCC-244 RAM Characteristics
(10 Volt Operation)

	DOSE (rads)			
	PRERAD	1×10^5	5×10^5	1×10^6
I_{DN}(mA)	4.0-5.0	4.0-5.0	3.0-4.0	2.0-3.0
I_{DP}(mA)	2.5-3.0	2.4-2.9	2.0-2.5	1.0-1.5
T_{AA}(ns)	150-240	150-240	250-350	500-750
T_{WW}(ns)	40-60	45-65	70-110	140-220
I_{DD}(μA)	.5-50	.5-50	1.0-110	1.0-110

Radiation hardness represents only one requirement for the part, and reliability is another major concern for use of these parts in a space system. A part qualification procedure has been established at Sandia for delivery of high-rel parts for either prototype development or to second source if necessary. The major features of this qualification sequence are listed in Table III.

The burn-in operation is a 150°C, 20 percent over-voltage static bias, 168 hour sequence that requires ≤ 5 percent part failure for lot acceptance. Lots exhibiting a 5 to 15 percent failure rate at first burn-in are permitted a second burn-in, but no third burn-ins are permitted. This burn-in cycle and PDA (percent defective allowable) is used to assure that the system can meet a 10-year

life requirement based on the normal assumptions of failure distributions and activation energies. The 150°C temperature is required to meet the reliability specification without resorting to excessive burn-in times.

To date, over 1200 parts of the 1802 family have been supplied for satellite systems demonstrating that the bulk CMOS technology is capable of meeting the severe environmental and reliability constraints imposed by space systems.

Table III
Part Qualification

Wafer Acceptance
Radiation Qualification
Ionic Contamination
SEM
100 Percent Die Visual
QC Verification
Die Shear and Bond Pull Qualification
100 Percent Prelid Visual
QC Verification
Preseal Bake
High-Temperature Storage
Temperature Cycle
Centrifuge
PIND Test
Fine and Gross Leak Test
100 Percent External Visual
QC Verification
First Electrical
Burn-in
High-Low Temperature Test
QC Final

Part procurement, however, requires not only that the technology be capable of meeting system objectives, but also that a design capability exist to support the system. This is essential for radiation-hardened parts, since the constraints imposed by radiation induced parametric shifts often have a deleterious effect upon circuit functionality. Many historical cases exist where commercial designs have been "hardened" by applying the proper process cycle only to discover that the circuit would not function due to radiation-induced parametric shifts. The explosive demand in the commercial semiconductor market is also increasing the difficulty in obtaining radiation-hardened designs for what typically are low-volume space applications.

To satisfy the present and future needs for custom parts for space and other government systems, Sandia has developed a silicon gate radiation-hardened bulk CMOS cell family with a corresponding CAD capability. The technology, referred to as the ELA (expanded linear array) cell family features a diffused p+ guardband for field isolation along the channel width direction and field shields for isolation between adjacent n-channel devices.[7] The standard cells are double ported. Presently, 18 standard cells have been designed, modeled, and characterized. Table IV lists the available cells and their width. The cell heights are 150 μm.

Table IV

ELA Standard Cells

Cell	Width (μm)
Asynchronous flip-flop-reset	300
Synchronous flip-flop-reset	280
Synchronous flip-flop-set/reset	320
Multiplexer	140
Inverting Buffer	60
2-input NOR	60
3-input NOR	80
4-input NOR	100
2-input OR	80
3-input OR	100
4-input OR	120
Exclusive OR	160
2-input AND	80
3-input AND	100
4-input AND	120
2-input n AND	60
3-input n AND	80
4-input n AND	100

The ELA technology has been used for the design and fabrication of an ELA test chip, ALU, and 1024 x 1 RAM. A 1024 x 8 ROM has been designed and is presently at the mask fabrication cycle. The RAM has a 10 volt, preradiation 100 ns access time. The performance of a megarad hardened part is typically less than a non-hardened part due to the increased device threshold voltages and reduced n-channel mobility.

The radiation response for several ELA cells is illustrated in Figure 1. This observed performance degradation for a total dose in excess of 1×10^5 rads

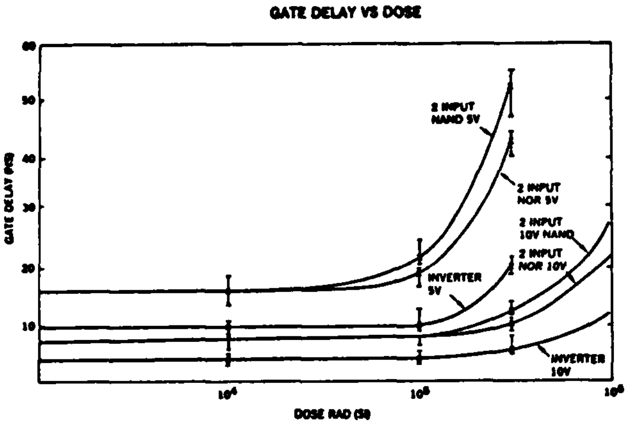

Figure 1

(Si) is a result of the substantial p-channel radiation-induced threshold voltage shift. I_{DD} is typically <100 μA for a hardened bulk CMOS LSI circuit under static bias and remains unchanged as a function of total dose up to exposures of 1 x 10^6 rads (Si).

Future (and even some present) system requirements will need an increased performance and packing density than that which is available with the present radiation-hardened bulk CMOS technology. To meet these new requirements, it is anticipated that process innovations such as refractory metal gates, recessed hardened field oxides, bipolar output drive circuits, and device scaling will be applied for a new generation bulk CMOS hardened technology. It is also important that these new hardened processes be compatible with commercial processes to fabricate the necessary technology transfer for volume procurement.

Summary

Microelectronic circuits for space systems generally have stringent requirements on device reliability, radiation hardness, and static power dissipation. The radiation hardened bulk CMOS silicon gate technology has successfully met these requirements in deliveries to several satellite programs. A proven technology, however, is only one aspect in obtaining the necessary circuits for special systems. Circuits must be designed and verified, especially for radiation environments, and second source capability must exist to ensure meeting schedule commitments. In many cases, this means that the user organization must own access to the mask sets. A radiation-hardened bulk CMOS silicon gate standard cell design package has been developed which permits an in-house design, prototype fabrication, design verification, and second source capability. This technology-design system has been successfully applied in processing high-reliability, radiation-hardened CMOS parts for DOE systems.

WRD:jc:4763A:5/18/80

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RADIATION-HARDENED CMOS/SOS FOR SPACE APPLICATIONS

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Current space applications impose tremendous demands on satellite digital electronics. Reliable, high speed circuits are required with stringent constraints on size, weight and power. These demands translate into high-performance, high density large scale integrated circuits that must also be immune to large total dose accumulations of radiation encountered from repeated passes through the Van Allen belt. In addition, military applications often insist upon devices which are insensitive to bursts of gamma and neutron radiation.

Complementary metal-oxide-silicon (CMOS) devices have high immunity to neutrons and offer the additional advantages of small size, light weight and low power. When CMOS arrays are processed appropriately (special channel oxide formation and subsequent low-temperature exposures), they can be made hard to large total doses. By combining CMOS circuitry with the silicon-on-sapphire (SOS) technology, one achieves higher speed, greater packing density, reduced dynamic power, and a dramatic decrease in sensitivity to bursts of gamma radiation. These advantages have been derived from the insulating sapphire substrate and the resultant minimization of P-N junction areas.

RCA is under contract with the Air Force to develop an LSI radiation-hardened CMOS/SOS general processor unit and associated circuits. Figure 1 shows photomicrographs of some of the chips in the family.

The heart of this chip set is a general processor unit (Fig. 2), which is an 8-bit parallel slice. The chip is slightly over 200 mils on a side, has about 2900 transistors, and has been produced at RCA by the standard and radiation hardened processes. Both types have been exhaustively tested by Questron Corporation and found to be functionally correct and to perform well.

All the members of the GPU chip family, shown in Table 1, are self-aligned silicon-gate CMOS/SOS circuits. They do not incorporate the special topological adjustments, such as tie down of silicon islands, that are employed to achieve the highest possible levels of total dose hardness. However, they have been designed with yield and manufacturability as prime requirements. They have been produced with the RCA-developed radiation-hardened CMOS/SOS process, and are expected to exceed total-dose hardness levels of 50,000 rads(Si) and transient hardness levels of 10^9 rads(Si)/s. These goals have been surpassed in the first two designs to be radiation tested, the GPU and RAM. All of the array types shown, with the exception of the Emulating Controller, have been produced and proven out using the standard CMOS/SOS process.

The GPU, RAM, and Multiplier are handcrafted custom arrays; the two controllers are standard-cell designs; and the ROM and GUA's are customized by using a single mask. Four GUA customizations have been successfully designed and produced for the Air Force and evaluated by Tracor, Inc. This chip set is being considered for several military systems.

A photomicrograph of the TCS 150, a 256x4 bit RAM, is shown in Fig. 3. While this chip is not outstanding in number of bits-per-chip, it has performed well under radiation.

Radiation data on several other RCA CMOS/SOS RAMs is presented in Table 2. These RAMs include the commercially available, standard processed, CDP 1821 and MWS5114, 1K and 4K static, random-access memories. The TCS 191, which is an earlier and larger version of the MWS5114, has been produced with the newer N+ gate rad-hard process.

Figure 4 shows a custom CMOS/SOS Arithmetic Logic Unit/Test Array that was designed using the special topological

adjustment for increasing the immunity to accumulations of gamma radiation. These topological adjustments include the tie-down of certain transistor silicon islands to a fixed potential and limiting the series stacking of transistors to three. There was an area penalty of about 15% for these topology adjustments.

The processing of CMOS/SOS arrays for enhanced tolerance to accumulated gamma radiation involves moderate changes from the standard silicon-gate CMOS/SOS process. The main differences are in the pyrogenic channel oxide growth, the avoidance of subsequent exposures to high temperatures, the formation of the doped-silicon gates, and the depositions of the field oxide and the aluminum. Radiation-hardened CMOS/SOS arrays have been produced using either P+ or N+ doped silicon gates. The N+ doping is preferred because of its higher conductivity.

Table 3 summarizes the radiation tests for the various array types. In the transient tests a 10-Mev Linac electron beam with both short and long pulses was used to determine the upset levels and transient annealing properties of the radiation-hardened TCS 129 GPU and the TCS 150 RAM. The GPU was exposed with both a dominant "0" and dominant "1" pattern stored in its 16 registers. Similarly, the RAM was exposed with dominant "1's" and "0's" stored in the four memory quadrants.

On the GPU the "carry out", the "all zero out", and two of the eight data outputs were monitored. On the RAM all four data-output lines were monitored. During the various operational modes a search was made for the worst-case upset condition. Observations were made during the low, high, high-impedance, and transition states. The other array types were tested only for sensitivity to total dose damage effects.

The four output waveforms in Fig. 5 are of the GPU in a normal mode without the presence of radiation. The DO(0) and DO(1) lines in Fig. 5a and 5b were presented on a digitizer scope. The output signals are shown varying from a high to a low state and then to the final high impedance state. The large spike in Fig. 5a is a normal transient generated within the device as the control logic is changed from an ADD to an AND function. A smaller spike in the DO(1) output is evident in Fig. 5b. The All-Zero-Output and the Carry-Out signals on dual-beam oscilloscopes are shown in Fig. 5c and 5d. A pin diode was used to normalize the dose rate. The supply-current surge is shown above the Carry-Out signal. Since the radiation pulse could be specified to occur anywhere in these waveforms, the worst-case conditions for upset to occur were determined.

Some typical upset responses are shown in Fig. 6. Temporary upset is the occurrence of a transient signal on any output line having an amplitude greater than 30% of the V_{dd} supply voltage and disappearing after the radiation pulse. Permanent upset is the change in state of stored data which can be corrected only by refreshing the original stored pattern in the registers. A comparison of the two data output line waveforms with those in Fig. 5 reveals that a change in state occurred during exposure to a dose rate of 1.4×10^{10} rads(Si)/s. An example of temporary upset occurring on the AZO and on the Carry-Out lines is shown in Fig. 6c and 6d. This example was the worst case, with only small transient signals occurring on the data output lines. The amplitude of the transient responses to the radiation pulse as shown on the AZO and CO lines is about 8 volts, the full V_{dd} supply voltage. The output recovers to its original state and is described as a temporary upset.

Table 4 lists the transient radiation results obtained with a 40-ns Linac pulse. Dose rates for both temporary and permanent upset are shown for the GPU and the TCS 150 RAM. The dose rates obtained with both stored patterns in the GPU are shown, the worst case being the "0" pattern. Although the upset levels were not determined precisely, they were at least a factor of two higher than those for the "0" pattern. All of these upset dose rates were measured for the worst-case operating conditions, which were established by varying the occurrence of the radiation pulse relative to the operation of the device. It was found that both temporary and permanent

average upset rates are above 10^{10} rads (Si)/s.

One of the objectives during this series of tests was to characterize the GPU transient annealing response — the ability to recover from a large dose per pulse and to resume operational status. Figure 7 shows the effect of a 27-kilorad pulse on a data output line. The subsequent shutdown of device operation was about 2 us, with 87% recovery of voltage amplitude within 20 us. The system requirements determine what the allowable recovery time may be. It was observed that the recovery time was a function of the dose per pulse and previous dose history.

One of the by-products of the transient tests was the measurement of total dose characteristics. These results, together with Co^{60} test results, are shown in Table 5. These arrays were produced with the p+ gate, radiation-hardened process. Failure did not occur after exposure for any dose for all three array types. The determination of functionality of a device under test was the same for the Co^{60} tests as the pulse tests. However, in the case of the TCS 125 array, a more comprehensive functional test, using the Datatron tester, was employed. These results clearly indicate a capability of 10^5 to 10^6 rads (Si) for these three array types.

Table 6 lists the Co^{60} test results for two memories fabricated with the standard, commercial, unhardened n+ gate process, and for the TCS 191 memory which was produced with an n+ gate, radiation-hardened process. The TCS 191 is electrically identical to the MWS5114 memory. The pass and fail doses for all samples are shown. On average the commercial memories failed at about 10 kilorads, while the radiation-hardened memory failed at an order-of-magnitude higher.

Cosmic rays which exist in space can induce soft errors in solid-state memory devices. These effects can occur in bipolar, NMOS, PMOS, and bulk CMOS or CMOS/SOS memories, including both static and dynamic types. A limited number of bulk CMOS types have been shown to latchup in a simulated cosmic ray environment. Table 7 lists some results of cosmic ray simulation experiments and analysis carried out with CMOS/SOS and bulk CMOS memories. The first three device types are RCA CMOS/SOS memories, whereas the fourth is a bulk type. The predicted error rates for these memories have been determined. Calculation of these rates is based on the experimental results and on an analysis which takes into account the sensitive volume of the memory storage cells, together with an assumed cosmic ray environment. The table lists the errors per day of each device for a space craft containing a memory system of 2.5×10^5 bits. The Mean Time Before Error is listed for each type. The SOS memories are about one to two orders of magnitude less sensitive than the bulk device and are immune to latchup.

SUMMARY

1. The test data have demonstrated that transient upset levels for the complex microprocessors and memories are 10^{10} rads (Si)/s, and that total-dose capabilities are in the range of 10^5 to 10^6 rads (Si).

2. The combination of special topological adjustment with radiation-hardened CMOS/SOS processing can guarantee a total-dose level of 10^5 rads (Si), with sufficient margin to reduce the need for a hardness-assurance program.

3. The high degree of immunity from soft errors induced by cosmic rays or alpha particles in CMOS/SOS memories, as well as the complete immunity from latchup, makes CMOS/SOS devices very attractive for space application.

4. Radiation-hardened CMOS/SOS LSI arrays should be seriously considered for use in future spacecraft applications.

TABLE 1

General Processor Unit CMOS/SOS Chip Set

ARRAY TYPES

• GENERAL PROCESSOR UNIT	TCS 129
• 256 X 4 RANDOM ACCESS MEMORY	TCS 150
• 2910 CONTROLLER	TCS 158
• EMULATING CONTROLLER	TCS 159
• 8 X 8 MULTIPLIER	TCS 196
• 1024-BIT READ-ONLY MEMORY	TCS 075
• GATE UNIVERSAL ARRAY – 300 GATE	TCS 090
– 452 GATE	TCS 091
– 632 GATE	TCS 092

TABLE 2

CMOS/SOS Random Access Memories

TYPE	CDP 1821 (COM'L)	MWS 5114 (COM'L)	TCS 191 (LARGE MWS5114)	TCS 150
ORGANIZATION	1024x1	1024x4	1024x4	256x4
POLY-SILICON DOPANT	N+	N+	N+	P+ OR N+
PROCESS	STD.	STD.	RAD HARD	RAD HARD

TABLE 3

Radiation Tests Conducted and Number of Samples Tested

ARRAY TYPE	SET UP	MONITOR	LINAC (10 MeV) 40 nsec PULSE TRANSIENT	LINAC (10 MeV) 40 nsec PULSE TOTAL DOSE	LINAC (10 MeV) 1.8 μsec PULSE RECOVERY	LINAC (10 MeV) 1.8 μsec PULSE TOTAL DOSE	CO^{60} TOTAL DOSE
TCS 129A RH GPU	LOAD 16 REGISTERS - 0 AND 1 PATTERNS	DO(0), DO(1), CO, AZO	5 (2 LOTS)	–	3 (3 LOTS)	4 (3 LOTS)	4 (3 LOTS)
TCS 150 RH 256 X 4 RAM	1 IN 0's, AND 0 IN 1's	DO(0), DO(1), DO(2), DO(3)	6 (1 LOT)	3 (1 LOT)	–	–	2 (1 LOT)
TCS 125 RH ALU	COMPLETE FUNCTIONAL TESTS		–	–	–	–	4 (3 LOTS)
TCS 191 RH 1024 X 4 RAM			–	–	–	–	5 (2 LOTS)
MWS 5114 1024 X 4 RAM			–	–	–	–	6 (7 LOTS)
CDP 1821 1024 X 1 RAM			–	–	–	–	9 (MANY LOTS)

TABLE 4

Transient Radiation Test Results 40 nsec Pulse

GPU
TCS 129A-RH

SAMPLE #	X 10^9 RAD (Si)/s 0 PATTERN TU	0 PATTERN PU	1 PATTERN TU	1 PATTERN PU
11	7-9	9	> 14	> 16
12	10-13	16	> 10	> 23
13	14	14	> 17	> 14
16	7-10	6-10	> 10	> 10
17	10-16	17-19	> 17	NO DATA
AVG	10-12	12-13	> 13	> 15

RAM
TCS 150-RH

SAMPLE #	X 10^9 RAD (Si)/s TU	PU
2	14	30-56
3	11	42-56
4	14	56-70
5	14	28
6	14	42-56
AVG	13	41-63

TU = TEMPORARY UPSET
PU = PERMANENT UPSET

TABLE 5

Total Dose Tests P+ Gate Rad Hard Process

GPU TCS 129A-RH SOURCE	SAMPLE #	FAILURE (K RAD)	RAM TCS 150-RH SOURCE	SAMPLE #	FAILURE (K RAD)	ALU TCS 125-RH SOURCE	SAMPLE #	FAILURE (K RAD)
1.8 μs PULSE	5 11 12 15	> 150 > 1,300 > 1,300 > 200	40 ns PULSE	1 5 8	> 800 > 1,400 > 1,700	CO^{60}	32 45 57 60	> 1,000 > 1,000 > 1,000 > 1,000
	AVG.	> 750		AVG.	> 1,300			
CO^{60}	1 10 18 19	> 200 > 1,000 > 1,000 > 1,000	CO^{60}	9 7	> 100 > 100			
	AVG.	> 800		AVG.	> 100		AVG.	1,000

TABLE 6

CO^{60} Total Dose Tests - Other RAM'S N+ Gate Processes

CDP 1821 1024 X 1 (COM'L) SAMPLE #	PASS-FAIL (K RAD)	MWS 5114 1024 X 4 (COM'L) SAMPLE #	PASS-FAIL (K RAD)	TCS 191 – RH 1024 X 4 (EARLY 5114) SAMPLE #	PASS-FAIL (K RAD)
1	10-11	1	8-12	1	500-1000
2	10-11	2	8-12	2	150-300
3	13-14	3	4-8	4	150-300
4	9-10	4	8-12	6	500-1000
5	13-14	5	8-12	10	50-100
6	9-10	6	4-8		
7	9-10				
8	19-20				
9	19-20				
AVG.	12-13	AVG.	7-11	AVG.	270-720

TABLE 7

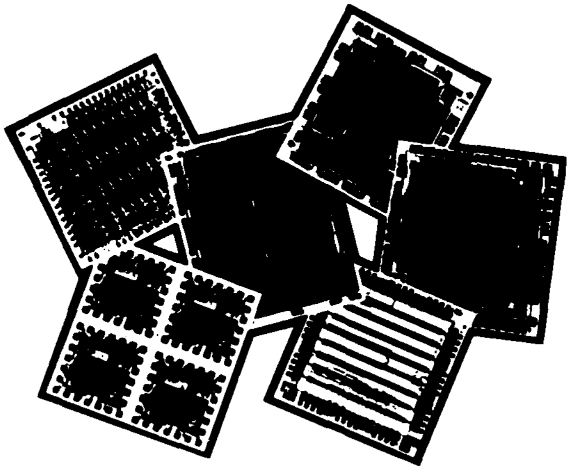
Effect of Cosmic Rays on Various CMOS/SOS and Bulk RAM'S

TYPE	FORMAT	PREDICTED ERROR RATE* (ERRORS/DAY)	MTBE (YEARS)
CDP 1821	1024 X 1	1.1×10^{-3}	2.5
TCS 146	4096 X 1	2.8×10^{-3}	1.0
MWS 5114	1024 X 4	17.0×10^{-3}	0.2
CMOS/BULK	1024 X 1	280×10^{-3}	0.01

*MEMORY – 2.5×10^5 BITS

FIGURE 1

Manufacturing Technology for Radiation-Hardened Microprocessor

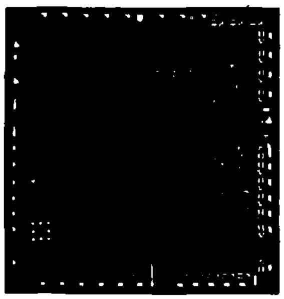


WPAFB/AFML

CONTRACT NO. F33615-78-C-5135
CONTRACT MONITOR ROBERT E. CONKLIN

FIGURE 2

General Processor Unit



5.2 X 5.5 mm (205 X 216 mils)

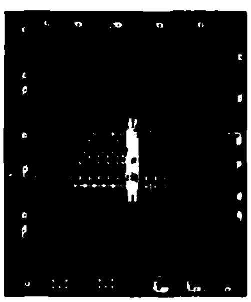
~ 2900 TRANSISTORS

TCS 129 GPU

- CMOS/SOS TECHNOLOGY
- FULLY STATIC OPERATION
- 8-BIT PARALLEL SLICE
- CONCATENATABLE
- < 125 nsec REG-TO-REG ADD

FIGURE 3

Random Access Memory



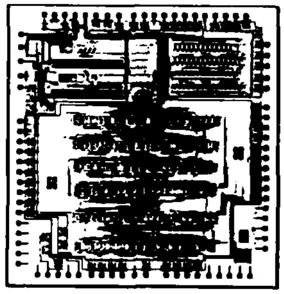
3.5 X 4.1 mm (136 X 163 mils)
~ 6000 TRANSISTORS

TCS 150 RAM

- CMOS/SOS TECHNOLOGY
- 256 X 4 ORGANIZATION
- INDUSTRY STANDARD PINOUT
- EASILY EXPANDABLE
- < 125 nsec ACCESS TIME

FIGURE 4

Arithmetic Logic Unit Test Array



8.6 X 8.1 mm (220 X 207 mils)

TCS 125 ALU TEST CHIP

- ARITHMETIC LOGIC UNIT
  - EIGHT BIT
  - CARRY OUT SIGNAL
- CELLS AND PHYSICS TEST CIRCUITS
- TOPOLOGICALLY ADJUSTED FOR MAXIMUM TOTAL-DOSE HARDNESS

FIGURE 5

Transient Test Output Waveforms - Normal

GPU TCS 129A-RH (SAMPLE #15 — PRE-RAD)

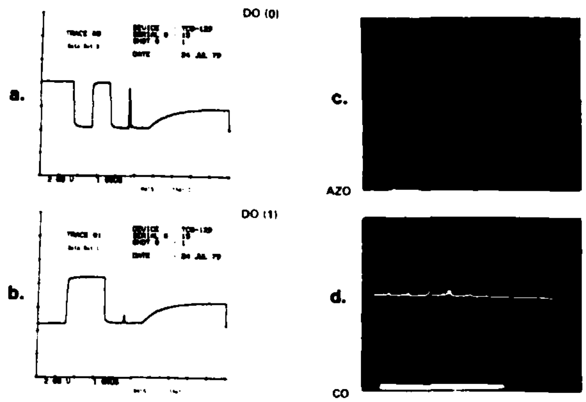
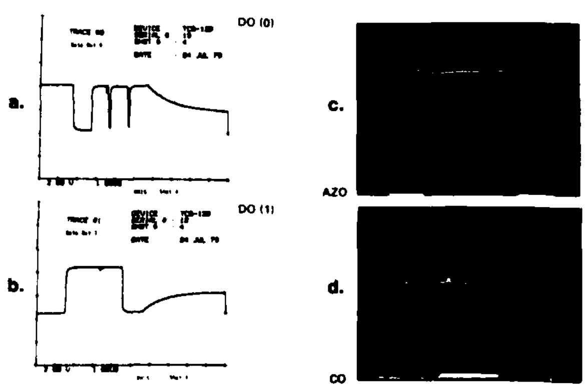


FIGURE 6

Transient Test Output Waveforms - Upset

GPU TCS 129A-RH (SAMPLE #15 — 40 nsec PULSE)

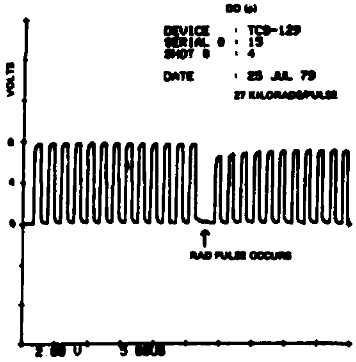


PERMANENT UPSET
SHOT 4 - 14 X 10^8 RAD (Si)/SEC

TEMPORARY UPSET
SHOT 9 - 8 X 10^8 RAD (Si)/SEC

FIGURE 7

Transient Annealing Tests - 1.8μ Sec Pulse
GPU TCS 129-RH



ELAPSED TIME AFTER PULSE	ALL OUTPUT LINES RECOVER TO
2 μ SEC.	> 63%
20 μ SEC.	> 87%

ADVANCES IN GALLIUM ARSENIDE INTEGRATED CIRCUIT TECHNOLOGY

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The principal requirements of a digital integrated circuit technology compatible with ultra-high speed large scale and very large scale integration are: (1) low chip area per gate, (2) low gate power dissipation, (3) extremely low dynamic switching energy, (4) high speed and (5) high process yield. The origins of these requirements are obvious. Large numbers of gates, in the 10^4 to 10^5 range, cannot be placed on a reasonable sized, approximately 1 square centimeter chip, unless the gate areas are small (<~ $1000 \mu m^2$). The power per gate must be well below 1 mW if chip dissipations are to remain manageable. The constraint on dynamic switching energy for high speed VLSI is especially severe because chip power dissipation must be maintained at high clocking frequencies. For example, assuming a maximum dissipation per 10^4 gate chip of 2 watts at an average gate clocking frequency of 1 GHz, the maximum allowing gate dynamic switching energy ($P_D \tau_D$) is 0.1 pJ. It is the purpose of this paper to report recent advancements in Rockwell's ion implanted, planar, GaAs integrated circuit technology and to demonstrate compliance between this technology and LSI/VLSI requirements.

The performance advantages offered by GaAs integrated circuits in the areas of speed and power dissipation places it as a prime candidate for the device technology of next generation military electronic systems. Advantages in both speed and power are derived from the superior material characteristics of GaAs when compared to silicon. The electron mobility in GaAs is approximately 5 times that in correspondingly doped silicon, and approximately 10 times the mobility of silicon grown on sapphire. The fabrication of GaAs integrated circuits in a semi-insulating substrate results in a reduction of stray capacitances leading to a significant improvement in power dissipation. These two factors; the high electron mobility of GaAs and the availability of semi-insulating substrate material form the basis from which GaAs integrated circuits, operating at significantly higher speeds and with much lower dynamic switching energy, can be derived.

Technology goals addressing LSI/VLSI circuits have provided the motivation for choosing a high yield planar fabrication approach and a low power Schottky diode FET logic (SDFL) circuit approach. The fabrication process capitalizes on the proven uniformity, reproducibility and low cost of implanting directly into semi-insulating GaAs for the formation of active device layers. The planar circuits are fabricated by using multiple localized ion implants permitting the active layers of Schottky diodes and FETs to be individually optimized. The planar MESFET is fabricated with two implants: one shallow, lightly doped n^- implant forming the channel region, and the other deeper n^+ implant forming the source and drain regions as shown in Fig. 1. In this manner, self aligned gates (L_g= 1 μm) requiring ≈ 0.75 μm alignment accuracy are formed having excellent device characteristics. The dielectric regions are utilized for post implantation annealing, protecting the GaAs surfaces during processing, and passivating the surface.

Inasmuch as GaAs Schottky-barrier diodes are among the fastest switching semiconductor devices existent and their switching energies (~10^{-15}J) and required areas (1 μm x 2μm active area) are very low, their use as logic elements in GaAs digital ICs is very desirable. We have developed a logic circuit approach using high speed switching diodes as the primary nonlinear logic element, with GaAs Schottky gate FETs used for inversion and gain as shown in Figure 2. This Schottky diode FET logic (SDFL) approach results in major saving of chip area compared to previous approaches in which FETs have been used as logic elements.

Great strides have been taken toward the successful development of GaAs integrated circuit technology. Improvements in processing techniques acquired from a better understanding of device physics as well as empirical experiments have provided processing results with better

uniformities and reproducibility than previously obtained. It is through these processing improvements that major accomplishments have been realized in demonstrated circuit performance. GaAs integrated circuit propagation delays have been measured as low as τ_d = 62 ps for L_g = 1 μm NOR gate ring oscillators. SDFL gates of only 600μm^2 have been fabricated and successfully operated. Power levels as low as 120μW/gate have been demonstrated, with dynamic switching energies as low as $P_D\tau_d$ = 27 fJ for L_g = 1 μm NOR ring oscillators, $P_D\tau_d$ = 16 fJ for L_g= 1 μm inverters have been measured, and circuit complexities in excess of 300 gates have been demonstrated.

Another ramification of the improvements in processing has been the ability to develop circuits of increasing complexity. Several circuits of MSI complexity have been fabricated and demonstrated to be 100% operational, as shown in Table 1. At the time of this writing, fabrication and testing of a 5 bit x 5 bit parallel multiplier (260 gates) and a 2 x 32 bit serial/recirculate serial shift register (550 gates) are in progress. Furthermore, an 8 bit x 8 bit parallel multiplier of approximately 1000 gates in complexity is expected to be demonstrated by July, 1980.

A review of electronic requirements for a variety of missions including air defense, ocean surveillance, theater surveillance, ballistic missile defense, ASAT tracking and imaging, ESM, intelligence, and military satellite communications, clearly dictates the requirement for VLSI complexity (≥10,000 gates). Within these missions, specialized circuits are required for a multitude of signal processing and communication tasks and VLSI computational and memory circuits common to many mission applications are needed. Extension of the GaAs technology into the VLSI range would make possible the fabrication of ultra high speed, low power integrated subsystems which cannot be produced using any other present IC technology.

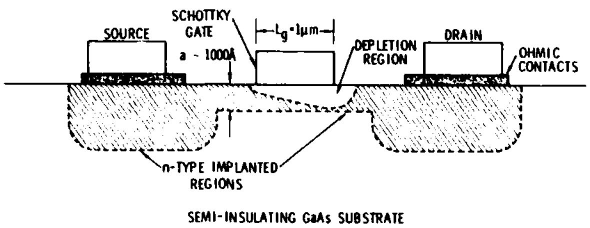
The impact to system's considerations in both increased capabilities and simplified system architectures is enormous. Algorithms of substantially increased sophistication could be performed in the same length of time, or solutions to processing tasks could be available within greatly reduced times. In terms of guidance and control systems, more elaborate processing algorithms translates to improved performance particularly in low contrast (night time) and smoke countermeasure engagements. Significant improvements in countermeasure immunity may be realized by permitting calibration, filtering, correlation, computation, computational verification and correction all within one control frame period. Computational availability in shorter periods of time reduces guidance error amplitudes and can be traded off with other subsystem specifications improving manufacturability and cost effectiveness of elements outside the electronic subsystem.

Data acquisition and storage processors common to surveillance missions can be greatly simplified by the existence of high speed memory. Multiplexing and demultiplexing circuitry required to achieve compatibility with lower speed memory could be greatly reduced. Furthermore, a high speed GaAs information preserving data compressor and subsequent decompressor could be utilized to reduce system memory requirements by a factor of between 2 and 4 depending on the application. When one considers that approximately 18,000 16K bit RAMs are required for certain applications, the savings of 9,000 devices per processor has a significant impact on both system reliability and system cost. It is important to note that memory, not computation generally determines processor size, weight and power.

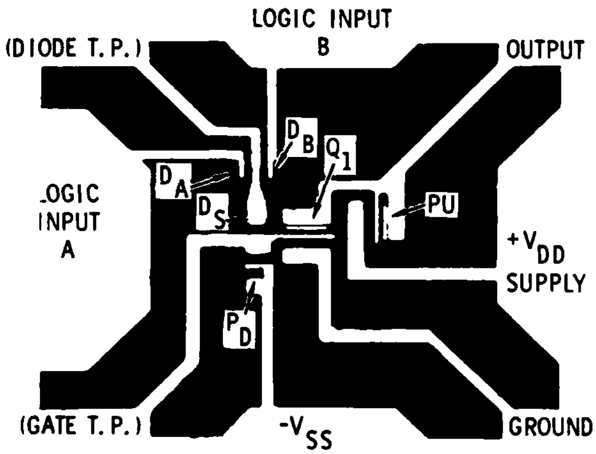
In computational systems, complex multiply-add operations often dominate timing considerations. In both air defense and ocean surveillance missions, computational throughput is determined primarily by the rate which Fast Fourier Transforms (FFT) can be performed. High speed operation can be traded off in a number of ways to improve system functional capabilities. The achievement of very complex ultra high speed GaAs VLSI circuits would define new dimensions in on-chip computational power. A 10^5 gate GaAs chip with τ_d = 100 ps operating in a pipeline processor would have, assuming

an $f_c = 1/5\ \tau_d$ clock frequency, a gate count-clock rate product of 2×10^{14} per second - a prodigious computation rate. The achievement of this level of GHz rate computational power in a low power integrated circuit could make possible systems approaches in high-speed signal processing, far beyond present electronic system's capabilities.

PLANAR GaAs FIELD EFFECT TRANSISTOR



W = 10 μm SDFL NOR GATE



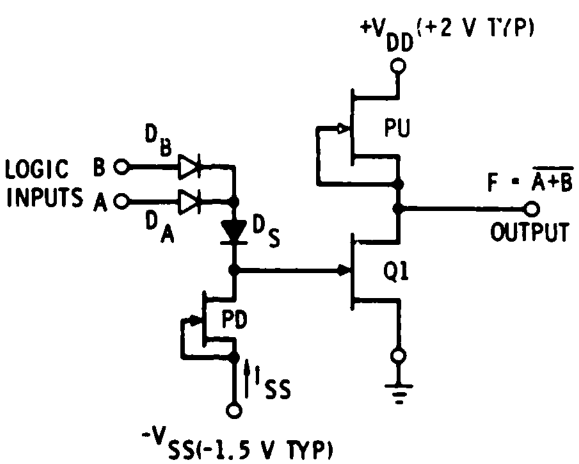


TABLE 1

REVIEW OF ROCKWELL PLANAR GAAS IC DEMONSTRATION CIRCUITS

	COMPLEXITY
FULLY DEMONSTRATED CIRCUITS:	
OR/NAND GATE, 3 PROPAGATION MODE RING OSCILLATORS, 5 & 10 μM	7 GATES
NOR GATE RING OSCILLATORS IN W = 3, 5, 10 & 20 μM WIDTHS	9 GATES
÷8 FREQUENCY PRESCALER (D-FLIP FLOP RIPPLE DIVIDER)	25 GATES
1 GHZ ANALOG SAMPLE/HOLD OR TRACK/HOLD CIRCUIT	25 GATES
÷8 SYNCHRONOUS COUNTER IMPLEMENTED WITH D-FFS	33 GATES
10/11 OR 20/22 VAR. MOD. DIVIDER FOR FREQ. SYNTHESIZER	37 GATES
4-BIT FAST RIPPLE CARRY ADDER USING 2 AND 3-LEVEL GATES	43 (63 EQUIV)
1:8 DATA DEMULTIPLEXER WITH ADDRESS GENERATOR	60 GATES
8:1 DATA MULTIPLEXER WITH ADDRESS GENERATOR	64 GATES
DIGITAL FM DEMODULATOR CIRCUIT	65 GATES
3 x 3 PARALLEL MULTIPLIER	75 GATES
8-STAGE SHIFT REGISTER/217 BIT P/N CODE GENERATOR	96 GATES
32 BIT SERIAL/RECIRCULATE SHIFT REGISTER	300 GATES
CIRCUITS AT FABRICATION/INITIAL TESTING STAGE	
5 x 5 PARALLEL MULTIPLIER	260 GATES
2 x 32 SHIFT REGISTER/DUAL 4.3×10^9 BIT P/N CODE GEN.	550 GATES
CIRCUITS AT LAYOUT/DIGITIZATION STAGE	
8 x 8 PARALLEL MULTIPLIER	1000 GATES

IMPACT OF VHSIC TECHNOLOGY ON AIR FORCE SYSTEMS

John M. Blasingame

AIR FORCE WRIGHT AERONAUTICAL LABORATORIES

The Very High Speed Integrated Circuits (VHSIC) program is a large ($200M), tri-service, new initiative to capitalize on new technological opportunities in very large scale integrated circuit technology to produce advanced weapon systems in the 1985-1990 time period. The program is organized as illustrated in Figure 1, showing the VHSIC Program Schedule, divided into four distinct phases. Phase 0 consists of a 9 months Program Definition study to analyze the various system candidates and partition these systems into functional modules. Commonality of these modules across as many systems as possible will be emphasized. Specific design and fabrication approaches for selected sets of these common modules (or chips) will be determined during the study phase and incorporated into a proposal for implementation in Phase 1 of the program. Nine contracts for the Phase 0 study were awarded on 7 March 1980 as indicated.

Phase 1 will narrow down to approximately 3-6 contracts to continue a three year development of 1.25 micrometer minimum feature chips as well as the development of a pilot line to produce these chips. In addition the feasibility of 0.5-0.7 micrometer minimum feature chips will be determined during Phase 1.

Phase 2 is a two year effort to take the 1.25 micrometer minimum feature chips produced in Phase 1 and incorporate these in electronic brassboards in order to demonstrate their operation in selected systems. In addition a pilot line will be developed for the production of chips with 0.5-0.7 micrometer minimum features.

Phase 3 is a concurrent effort to concentrate a number of relatively small contracts on special problem areas which provide support technology to the main program.

The overall objectives for the VHSIC program as a whole are given in Figure 2.

The system candidates which will be analyzed in Phase 0 are listed in Figure 3. There are a number of similar systems within the three services, ie: each service has a communication system, an image processor system, plus an electromagnetic warfare system; several services have a tactical as well as a surveillance radar signal processor, missile guidance system and general purpose computers. All 20 systems will be considered during the course of Phase 0.

The specific technologies being investigated are listed in Figure 4. Many companies chose to investigate several technologies, since it is not obvious at this point that any specific one will meet all the goals of the VHSIC program.

Figure 5 illustrates the overall goal of the program--- to reduce a signal processor which might take a box of 7 each 6 X 9 inch circuit boards and reduce this to just one chip with VHSIC technology.

Figure 6 illustrates some of the key technology that is required to achieve the revolutionary capabilities of VHSIC chips. Certainly one of the most important will be the use of electron beam lithography--- either by focused electron beams drawing directly on the surface of a resist coated silicon wafer or by generating a master mask of high resolution (ie:0.5 micrometer minimum feature size with ± 0.1 micrometer resolution) which can be printed on the silicon wafer by a flood beam of X-rays. The scanning electron-beam micro-fabricator type of machine possesses enormous potential for application in the VHSIC program because it can be programmed directly by a computer. Indeed, the application of an entire hierarchy of computer aided system analysis, through computer aided design, computer aided lithography, computer aided manufacturing, and computer aided testing is crucial to the success of the entire VHSIC program.

Figure 7 illustrates the status of integrated circuit technology in 1980 at about the 16 bit microprocessor or 65K RAM memory level with the 3-5 micrometer optical lithographic technology available today. As the VHSIC program progresses toward the goal of 0.5 micrometer minimum feature size devices, we should see 32 bit microprocessors with 1MB memories in the late 1980s.

Figure 8 shows the ultimate physical limits for how far microelectronic technology can push integrated circuits in terms of speed and power, if limited in power dissipation to about 2 watts per centimeter square chip. The speed of light across the chip represents one ultimate barrier which cannot be exceeded. The thermal noise generated at any given temperature (ie: room temperature shown) represents another fundamental barrier. In addition the quantum mechanical limit given by information theory serves as an ultimate barrier. The goal of the VHSIC program of 10^{13} gate-clock cycles is shown in relation to some of the best device performance reported to date for silicon and gallium arsenide depletion mode MESFET discrete devices with 1.0 micrometer gate structures. One can observe from this figure that there is considerable room for improvements in integrated circuits from a fundamental point of view, but that one is rapidly limited by the lithographic technology when forming more gates per unit area on a chip.

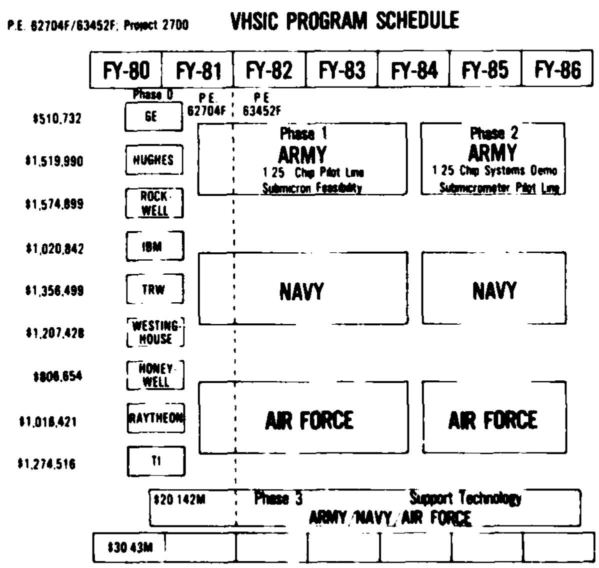
An analysis of current radar systems and their processor requirements has been performed by Hines and Bick and was reported at the November 1979 West Coast Computer Conference. The following illustrations are taken from their analysis. Figure 9 shows the typical cost distribution in a large airborne radar system. Note that the largest component cost is in the signal processor (about 26%). Thus, this component rapidly becomes the limiting item for improvement of radar systems. Figure 10 illustrates the parameters for a typical flying aircraft radar processor of today. Future tactical fighter planes may require radars which operate in additional modes. Figure 11 shows the required machine parameters for a radar processor for the four tactical modes of (1)air/air search and track, (2) IFF, (3) air/ground SAR/ GMTI, and (4) terrain following/terrain avoidance. Using state-of-the-art LSI/ECL, radar processors have been constructed with characteristics as shown in Figure 12. This represents an extremely expensive processor which is generally unacceptable for a tactical fighter.

The capabilities of a processor constructed with 1.25 micrometer minimum feature VHSIC chips, such as should become available in 1984, are shown in Figure 13.

Future requirements for tactical fighters including reconnaissance capability with synthetic aperature techniques are shown in Figure 14. The capabilities achievable by a radar processor made from 0.5 micrometer minimum feature VHSIC chips, such as should be available in 1986, are shown in Figure 15. Thus by the late 80's VHSIC technology should approach the capability of meeting the Air Force 1980 requirements for tactical fighter with reconnaissance capability as shown in Figure 16. Without VHSIC this capability would be totally impossible.

If we look at the radar processor situation another way, we can reduce the integrated circuit count and improve the reliability and performance of today's existing radars, as shown in Figure 17. Similar results have been predicted from the analysis of other types of Air Force systems across the board.

In summary, Figure 18 shows some recommendations which follow from the VHSIC program, which likewise should apply to all Air Force electronic systems.



MAJOR OBJECTIVES OF VHSIC

- PROCESSING SPEED x 50 to 100
- SIZE, WEIGHT, POWER, FAILURE RATE, & LIFE CYCLE COST x 1/10
- NEW ARCHITECTURE TO MINIMIZE CUSTOMIZATION
- FAULT TOLERANT DESIGN BUILT IN TEST (BIT)
- CAD FACILITY
- VHSI PILOT LINE(S)
- LITHOGRAPHIC MACHINE FOR 0.5 MICRON
- MIL SPEC QUALITY VHSIC CHIPS
- CHIP SETS FOR SYSTEM DEMO'S

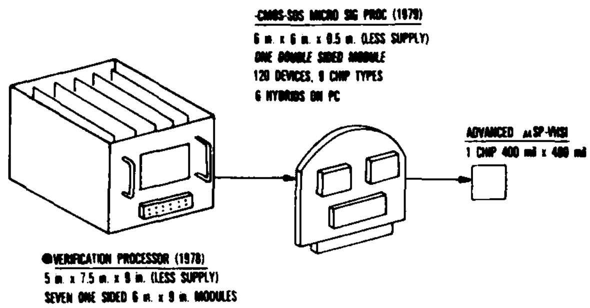
VHSIC SYSTEM DEMONSTRATION CANDIDATES

AIR FORCE	NAVY	ARMY
TAC RADAR SIG. PROC.	TAC RADAR SIG. PROC.	----
COMM. SIG. PROC. (JTIDS)	COMM MODEM	BATTLEFIELD INFO. DIST. TECH.
G.P. COMPUTER AN/AYK-15A	G.P. COMPUTER AYK-14/UYK-20	----
CRUISE MISSILE GUIDANCE	----	FIRE & FORGET MISSILE
ADV. POWER MGM. (EW)	ESM SIG. SORTER	EW WEAPON TARGETING
ADV. ONBOARD SIG. PROC. (SATELLITE)	DIG. IMAGE PROC.	ADV. FLIR TARGET ACQ.
ADV. MED. RANGE AIR TO AIR MISSILE	----	----
UNIVERSAL SIG. PROC. (E-3A)	AIR/SHIP SURV. RADAR	----
	PROG. ACOUSTIC SIG. PROC.	
	NATO IDENTIFICATION.	

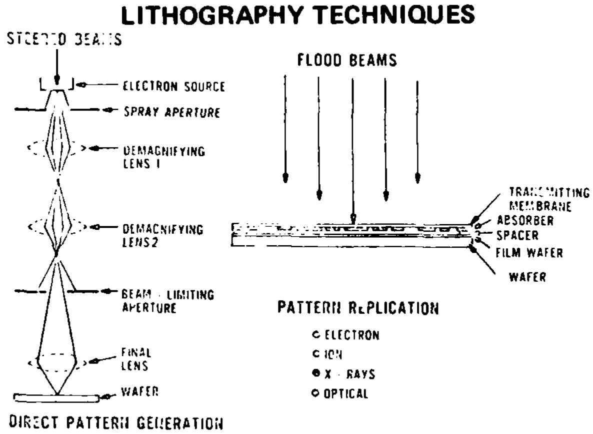
PRIMARY PROCESSING TECHNOLOGY

I²L	BIPOLAR	NMOS	CMOS BULK	CMOS SOS
	X	X	X	
	X		X	
	X			X
X		X		
				X
X		X		X
		X	X	X
	X			
X		X		

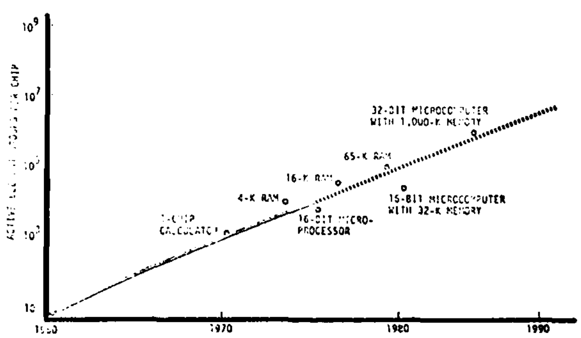
MICRO-SIGNAL PROCESSOR EVOLUTION TO VHSI



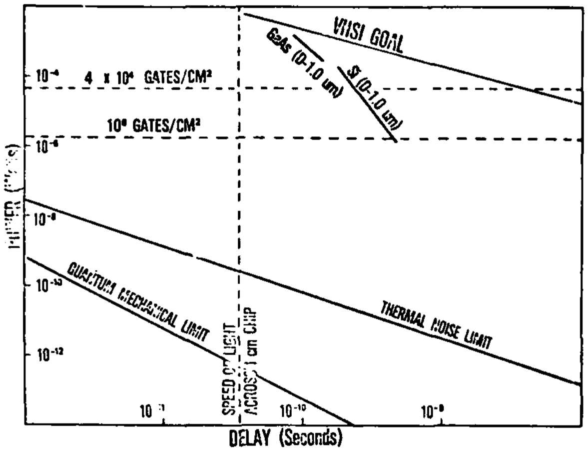
LITHOGRAPHY TECHNIQUES



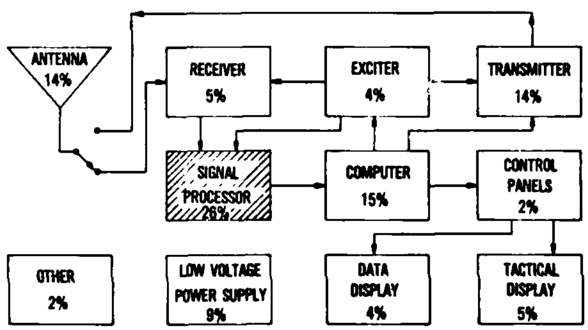
PROGRESS IN INTEGRATED CIRCUIT DEVICES



SPEED POWER



TYPICAL RADAR SYSTEM COSTS DISTRIBUTION



TYPICAL FLYING PROCESSOR

ARCHITECTURE:	PIPELINE/PARALLEL PIPES
	1.2 MBIT MEMORY
ARITHMETIC:	COMPLEX (12 + J12)
SPEED:	70 MOPS (MULTIPLUS/ADDS)
IC COUNT:	4000
POWER:	1 KW
SIZE:	~ 1 CUBIC FT.

REQUIRED MACHINE FOR FOUR TACTICTAL MODES

ARCHITECTURE:	PIPELINE/PARALLEL PIPES
	12.5 MBIT
ARITHMETIC:	COMPLEX (12 + /2J)
SPEED:	200 MOPS (MULT + ADDS)
IC COUNT:	1000
POWER:	1 KW
SIZE:	~ 1 CUBIC FOOT

6.3 R&D MACHINE PARAMETERS

ARCHITECTURE:	PIPELINE/PARALLEL PIPES
	12.5 MBIT MEMORY
ARITHMETIC:	COMPLEX (12 + J12)
SPEED:	180 MOPS (MULTIPLUS + ADDS)
IC COUNT:	2500
POWER:	~ 3 KW
SIZE:	1 CUBIC FOOT

VHSIC PHASE 1 PROCESSOR

ARCHITECTURE:	PIPELINE/PARALLEL PIPES
ARITHMETIC:	COMPLEX (12 + J12)
SPEED:	200 MOPS
IC COUNT:	500
POWER:	1 KW
SIZE:	1 CUBIC FOOT

TACTICAL FIGHTER WITH RECON

ARCHITECTURE:	?
	16 BILLION BITS MEMORY
ARITHMETIC:	FLOATING POINT
SPEED:	2000 MOPS
IC COUNT:	1000
POWER:	1 KW
SIZE:	1 CUBIC FOOT

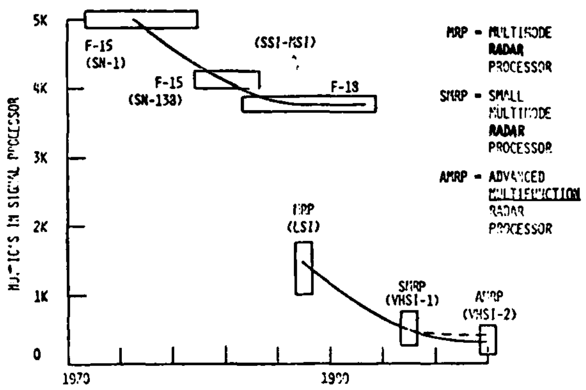
VHSIC PHASE II MACHINE

ARCHITECTURE:	?
	MEMORY 16 BILLION BITS
ARITHMETIC:	FLOATING POINT
SPEED:	2000 MOPS
IC COUNT:	2500
POWER:	5 KW
SIZE:	1 CUBIC FOOT

SENSOR PROCESSING ARCHITECTURE FOR RADAR

PROCESSORS	CAPABILITY	SPEED	PHYSICAL CONSTRAINTS
TODAY 70 MOPS 7.5 MHz CLOCK 10^5 WORD MEMORY	AA/ST NCID TF (AUSTERE) A/G RB	RT	1 KW 1 FT^3
VHSIC I 200 MOPS 20 MHz CLOCK 10^6 WORD MEMORY	AA/ST NCID TF/TA A/G SAR (512x512) GMTI/L	RT	1 KW 1 FT^3
VHSIC II 2000 MOPS 200 MHz CLOCK 10^9 WORD MEMORY	AA/ST NCID TF/TA STRIKE: A/G SAR (5Kx5K) GMTI/L TS/TC	RT	1 KW 1 FT^3
	RECCE: A/G SAR (10Kx10K) TS/TC	NRT	

REDUCTIONS IN RADAR PROCESSOR IC COUNT



RECOMMENDATIONS

- VHSICs Avoid Custom Designs & Thereby Lower Overall System Costs
- Design Costs Will Be Less Due to VHSIC Enhanced CAD Capability
- New Lithographic Capability from VHSIC Will Help Improve Yields & Lower Costs
- Processing Costs/Function Will Be Less for VHSICs Because of Higher Density
- Commonality of VHSICs Across Many Army, Navy & Air Force Systems Will Reduce System Design Costs

AN INTEGRATED DESIGN AND MANUFACTURING APPROACH TO VLSI

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Hopewell Junction, N.Y. 12533

In the early 1970's, IBM recognized the design and manufacturing problems associated with the exploitation of VLSI for main frame computer microelectronics. The IBM design philosophy, which encourages end product designers to personalize the logic in a given design to uniquely satisfy the specifications of that end product, was not to be changed. Therefore, projects were put in place to develop a design capability that would permit the design of LSI components (and extendable to VLSI components) anywhere in the corporation consistent with technology design constraints, manufacturing constraints and quality constraints.

Two design approaches were available. The first, a custom design, supports a unique design tuned to the product specifications while maximizing silicon usage. Both the design time and the qualification time of custom designs are measured in months. Design support normally consists of interactive design aids. Because of the cost and length of time required for design and qualification of custom chips, it was decided to restrict this approach to a few special high-volume part numbers.

An automated design approach was selected as the "work horse" for LSI chip design. A "masterslice" or gate array chip design is coupled with a turnkey design system to minimize the manual design effort while assuring the manufacturability and quality of the custom personalized chips. This approach minimizes design and qualification cost and time at the expense of design constraints to achieve automation.

Manufacturing initially had a number of concerns about such an automated design-release system. First, it needed the capability to determine the manufacturability of each part number at the time of release of that part number; next, it needed the ability to guarantee the quality and reliability of these parts; and lastly, because its process lines will evolve with time, it needed the ability to assess the reproducibility of these parts over time.

These concerns were addressed by first establishing procedures for systems integration and control, and secondly, a manufacturing audit capability. Systems integration and control essentially put engineering level control on the parts as well as the whole of the design and release system. The programs, the technology design rules, the process design rules, and the design methodology are qualified by an independent assurance organization before a new technology is made available to end product designers. Changes and enhancements are also qualified before they are released to the users.

The audit function verifies the goodness of the design data by checking the integrity of the design data, the engineering control levels of technology rules, process rules, and design tools used, and the design methodology. Automatic qualification is granted a part number if the released data audit is successful.

There are five steps required to design a chip with the design system. Although constraint of designing for testability impacts the initial logic design, the logic entry function and design verification are free of constraint and are essentially technology independent. Physical design is constrained by the technology design rules and the masterslice layout. One of the prime considerations in masterslice layout is the wirability of the chip. A prediction of the required number of wiring channels--considering the average number of connections per circuit, the average connection length, the number of circuits, and the blockage per connection for macros--is made early in the design of the masterslice. A tradeoff is made between the acceptable confidence level for wirability and the amount of silicon area dedicated to wiring. This tradeoff is critical because it has been shown that one or two wiring channels per cell can make the difference between wirability and non-wirability.

The automated physical design subsystem uses the following strategy for the physical layout. First, automatic placement including a crude iteration of global wiring demand, is completed. Technology ground rules such as capacitive loading and live voltage drops are considered in this phase. Next, global wiring is completed with iteration on placement if required; and finally, automatic point-to-point wiring is accomplished. Additional technology design rules are considered in this phase. Complex logic chips can be designed in a matter of days using this approach, with all technology design rules checked in the process. A logical-to-physical verification is also made.

In test generation the design is verified to be consistent with the design rules for testability. DC stuck fault patterns are then generated. Delay test patterns can also be generated if required. Testability coverage is calculated during this process, and generally that coverage will be between 95-100%.

The design data is then formatted in the release subsystem for release to manufacturing. In the manufacturing release system, the audit function is run, and if successful, the part number is accepted and granted qualification. The release system also processes the design data to generate the necessary numerical control instructions to drive process tools and testers on the production line.

The design-release-manufacturing system complex has been used to design and release thousands of custom personalized chip designs during the past several years. The audit of the design, including test pattern verification, can be accomplished in minutes compared to days or weeks for manual designs. The quality of the design data, as measured by zero wafer yield attributable to bad design data, has been excellent. Less than 0.1% of released parts have had zero yield because of errors in the design data. VLSI technologies will be designed and manufactured by extending this system.

<u>Conclusions</u>

1. Masterslice or gate array chips can be designed efficiently and effectively with turnkey design systems.

2. Checking functions and methodology controls can be implemented so that manufacturability and quality can be assured.

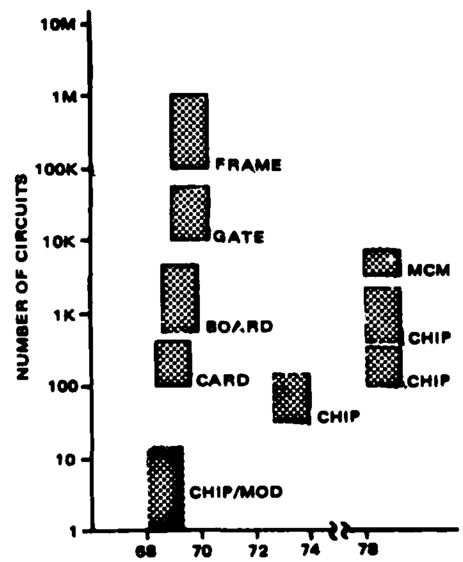
3. These design systems are extendable to VLSI.

<u>Recommendations</u>

1. Gate arrays should be studied as a technology vehicle to efficiently and effectively design low-volume microelectronic parts.

2. An integrated design and manufacturing system should be used to support the gate array chip technology. Such an integrated system should be part of a total technology definition.

LOGIC TECHNOLOGY EVOLUTION



LSI DESIGN CHALLENGE

DESIGN LSI COMPONENTS ANYWHERE IN CORPORATION CONSISTENT WITH

- TECHNOLOGY DESIGN CONSTRAINTS
- MANUFACTURING CONSTRAINTS
- QUALITY CONSTRAINTS

TWO DESIGN APPROACHES

CUSTOM DESIGN	AUTOMATED DESIGN
• BAG OF TOOLS	• TURN KEY SYSTEM
• MAXIMIZE SILICON USAGE	• MINIMIZE MANUAL DESIGN EFFORT
• UNIQUE DESIGN TUNED TO MEET SPECIFICATIONS	• IMPOSE DESIGN CONSTRAINTS TO ACHIEVE AUTOMATION
• FEW PART NUMBERS	• MANY PART NUMBERS
• HIGH VOLUME	• LOW VOLUME
• SPECIALS	• MASTER SLICE

CONCERNS

MANUFACTURABILITY OF FIRST ORDER

QUALITY

RELIABILITY

REPRODUCIBILITY

APPROACH

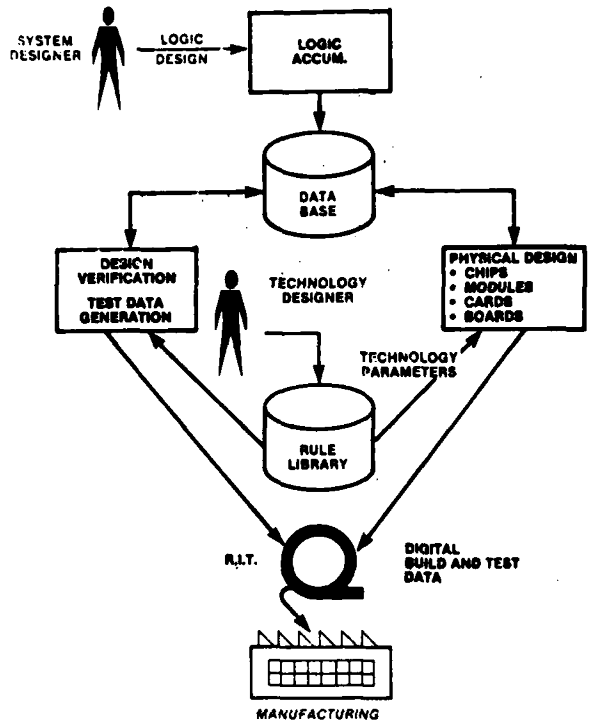
CHECKING OF

- DATA INTEGRITY
- TECHNOLOGY DESIGN RULES
- PROCESS DESIGN RULES
- DESIGN TOOLS
- DESIGN METHODOLOGY

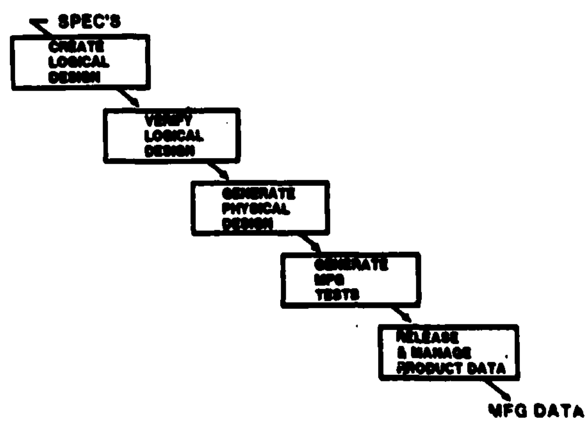
BY

- SYSTEM INTEGRATION AND CONTROL
- AUDIT FUNCTION

BASIC EDS FLOW



FIVE STEPS TO MFG VIA EDS



PHYSICAL DESIGN

WIREABILITY ANALYSIS

EARLY IN CHIP DESIGN

CONSIDERS FOLLOWING PARAMETERS

- AVG. NUMBER CONNECTIONS/CIRCUIT
- AVG. CONNECTION LENGTH
- NUMBER CIRCUITS
  AVG. BLOCKAGE/CONNECTION (MACROS)

RESULT

NUMBER OF WIRING CHANNELS FOR CONFIDENCE LEVEL

EXPERIENCE

AUTOMATIC PLACEMENT AND WIRING

STRATEGY

AUTO PLACEMENT INCLUDING CRUDE ITERATION OF GLOBAL WIRING DEMAND

GLOBAL WIRING

AUTO WIRING

EXPERIENCE

CHIP DESIGN – DAYS vs MONTHS

TECHNOLOGY GROUND RULES CHECKED

TEST GENERATION

DESIGN RULES TO INSURE TESTABILITY

STRATEGY

- VERIFY DESIGN CONSISTENT WITH RULES
- GENERATE DC STUCK FAULT PATTERNS
- PREDICT FAULTS AND IMPACT ON FUNCTION
- GENERATE ADDITIONAL STUCK FAULTS AS APPROPRIATE
- GENERATE DELAY TEST PATTERNS

RELEASE SYSTEM

AUDITS DATA AND GRANTS QUALIFICATION

GENERATES NUMERICAL CONTROL INSTRUCTIONS FOR PROCESS TOOLS AND TESTERS

IBM EXPERIENCE

DESIGN TIME

- DAYS VS MONTHS

MANUFACTURABILITY VALIDATION

- DAYS VS. MONTHS

QUALITY OF DESIGN DATA

- $<$ .1% OF RELEASED PARTS HAVE BAD DESIGN DATA

HIGH DENSITY LSI PACKAGING WITH HERMETIC CHIP CARRIERS

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ABSTRACT

The trend in semiconductor technology is to reduce cost per function by providing more components on a single chip. The increased number of functions per chip also increases the number of input/output connections (I/Os) per chip. Increased chip complexity and I/Os have several effects: an increased requirement to pretest and screen before interconnecting multiple chip assemblies and a need to improve the performance and packaging density of heretofore acceptable dual in-line packages (DIPs).

Compared to DIPs, the hermetic chip carrier (HCC) has better high frequency characteristcs and a 5:1 improvement in packaging density. The HCC is being standardized by JEDEC in both 40 and 50 mil center-to-center I/O spacing in families with up to 156 I/Os. Tooling of both HCCs and test burn-in sockets with 84 I/Os is available.

Applications of HCCs at the module level demonstrate the 5:1 packaging density improvement. Design, assembly, and test methods are reviewed for both single and double sided assemblies. Results of environmental tests are given. Advantages of the packaging system are shown. Conclusions are derived and recommendations for future activity given.

INTRODUCTION

The trend in semiconductor technology of providing more components on a single chip has effectively reduced the cost and improved the reliability per function. These two advantages of larger scale integration (LSI) open up new applications of electronics and allow an increased number of functions per chip for electronic intensive applications.

However, as the number of components per chip increases, the number of I/Os increases and the popular DIP and flatpack packages are too wasteful of space and weight. The hybrid packaging engineer eliminates standard packages by attaching many bare chips to a thin- or thick-film substrate with leads bonded from chip to conductors on the substrate. The unit is then hermetically sealed in a larger package. Fewer connections are brought out of the hybrid than are connected internally. Packaging density improvement of 10:1 is usual with hybrid packaging compared to single chips in standard packages. As long as system complexity requires multiple chips to perform a complete system function, a requirement will exist to interconnect chips by hybrids in high density packaging applications.

PROBLEMS WITH COMPLEX HYBRIDS

Although hybrid packaging provides high density with attendant volume and weight reduction, the difficulty of constructing and testing reliable hybrids has increased with the complexity of the chips. It has become more difficult to achieve high yield because of the inability to adequately screen and test chips and substrates before assembly, and because wire bonding assembly itself is not always a high yield process. These problems, which reduce yield and raise costs, are further compounded by the problem of repair after sealing (opening the large hermetic seal, repairing the chip, and then resealing to hermetic conditions). Repair can only be accomplished by skilled people in a special hybrid facility.

Other solutions to chip and wire hybrids have been tried in an attempt to solve the various problems. The passivated beam-lead or tape bonded chip has not gained favor because of a variety of technical difficulties which have not yet been solved, plus two additional problems — one associated with mature chips, the other with new chips. Mature chips of a generic type produced by different manufacturers are modified to their own designs and processes to improve chip yield, thus they differ in detail. Because they do not have the same I/O pad placement, they will not fit the same substrate bond pattern in the case of beam leaded chips, or the same tape in the case of tape bonded chips. In addition, adequate mechanisms are not available to screen out defective chips by burn-in or other means before committing to a multiple chip hybrid. New chips with a large number of I/Os are generally not made with beam leads or tape bonded. Rather they are made with standard pads for wire bonding. The new chips, with great complexity and many I/Os, generally do not have the maturity of experience to provide high yield and must be thoroughly screened and tested before final assembly. Three major requirements must be met for producing complex high density hybrids with high yield:

1. 100% screening and test of semiconductors.

2. 100% test of substrates.

3. High yield final assembly mechanism of semiconductors to substrate.

All three conditions are met by mounting chips in ceramic leadless HCCs and assembling and interconnecting the HCCs on multiple-layer, thick-film, hybrid substrates.

A typical 48-lead DIP is compared to a 48-lead HCC in Figure 1, which directly illustrates the improvement in packaging density and indirectly the improvement in circuit characteristics provided by the reduced inductance and capacity of leads from the chip to the package leads. Typical results of tests at RCA indicate that digital clock rates are limited to under 500 MHz by the DIP whereas time delay reflectometer (TDR) measurements of the HCC show potential operation to 4 GHz with standard carriers and above that with specially designed carriers.

Chips can be mounted and connected singly in a chip carrier or, for purposes of standardizing the types of carriers, multiply mounted and connected in groups of three or four in a larger chip carrier as shown in Figure 2. This view shows a typical assembly of chips in chip carriers mounted and interconnected on a multiple layer thick-film substrate. The chip carriers have not been hermetically sealed by covers in order to show the arrangement. In the production assembly the chips would not be visible. In the case of the single chip per carrier, chips are mounted on the carrier, and all I/Os on the chip are connected directly to the inner leads of the chip carrier. In the case of the multiple chips per carrier, chips are mounted on a 7 mil ceramic substrate with single-layer gold, thick-film patterns to provide an intermediate connection between chip bond out and package bond out which reduces the wire lead length and prevents wire crossovers. Most chip I/Os are bonded out. A few paths such as power and ground are common, as would be in a larger LSI. In some few cases where the number of outside leads is limited, chip to chip connections are made internal to the package. Thus, most of the I/Os are available for connection to electrical test.

FABRICATION COMPARISON

Fabrication of a conventional hybrid is a sequential operation; i.e., one must have the substrates, then all of the chips. The assembly process commences with die bonding and wire bonding, followed by substrate attachment to the package and then the first electrical test. Two basic problems arise: (1) for complex chip and wire hybrids it is virtually impossible to completely test the substrate by automatic equipment because adequate test probe fixtures cannot be made to match the small bonding pad dimensions; and (2) the first time the active devices and substrate are completely tested is in the assembled unit at the first electrical test. If either the substrate or any of the devices is defective, a large repair operation

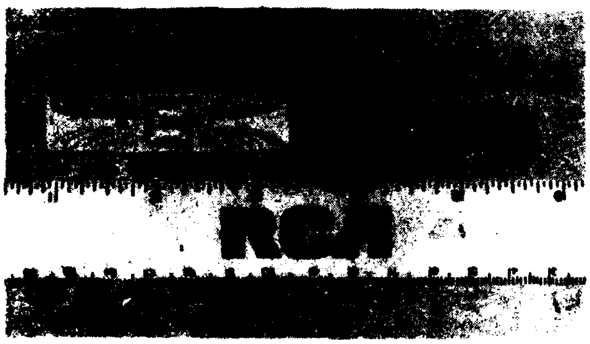

Figure 1. Comparison of 48 Pin Dual In-line and 48 Pin Leadless Hermetic Packages

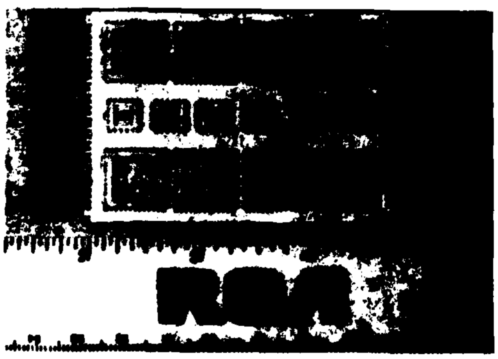

Figure 2. 40-Chip Single-Sided Hybrid (TLM)

begins. In contrast, chip carrier fabrication is a parallel operation of chip assembly and test with substrate fabrication and test, as indicated in the simplified flow chart of Figure 3.

CHIP AND SUBSTRATE PREPARATION

The hybrid manufacturer can buy or fabricate parts that have been tested both statically and dynamically and have been burned in. Indeed, devices in chip carriers can be obtained to whatever quality level the user requires. Single devices in chip carriers are readily tested using the same testers and programs

as presently exist on standard IC testers. Multiple chips in chip carriers are easily tested by a simple reprogramming of most standard IC testers. Burn-in sockets, cards, and frames are available for components in chip carriers, as shown in Figure 4.

A necessary consideration in fabricating large, complex, multilayer substrates (with more than 500 interconnections and interconnecting 20 or more 48-pin chip carriers containing many LSI devices) is that all substrates must be tested for continuity and isolation of all nets. The greater the substrate complexity, the greater the need to perform electrical tests. This testing is very difficult and expensive to implement with conventional chip and wire substrates because the small pad spacing requires a complex custom probe setup. On the other hand, the pad spacing for mounting chip carriers allows fixturing in pogo-pin testers, as illustrated in Figure 5. The pins are connected to an automatic continuity and isolation tester; continuity and isolation parameters are programmable. Testing of substrates with this kind of tooling can generally be completed in less than a minute.

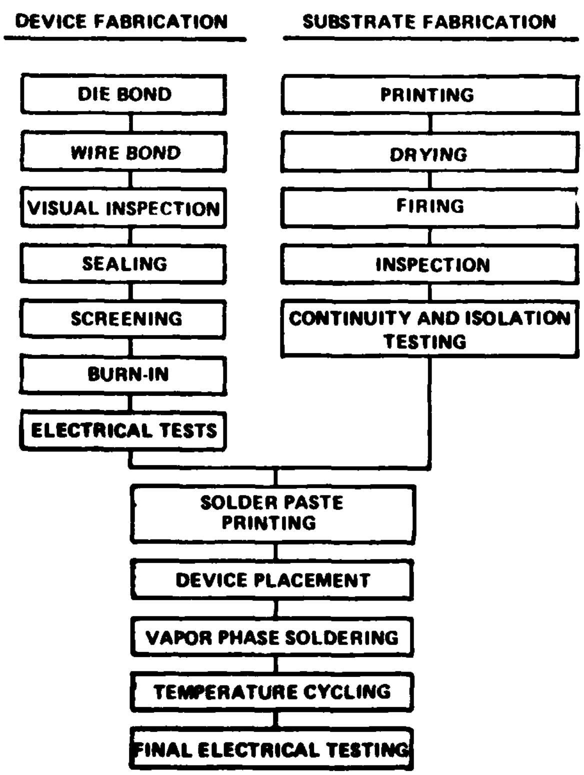

Figure 3. Simplified Chip Carrier Fabrication Flow Chart, Showing Parallel Operations for Devices and Substrates

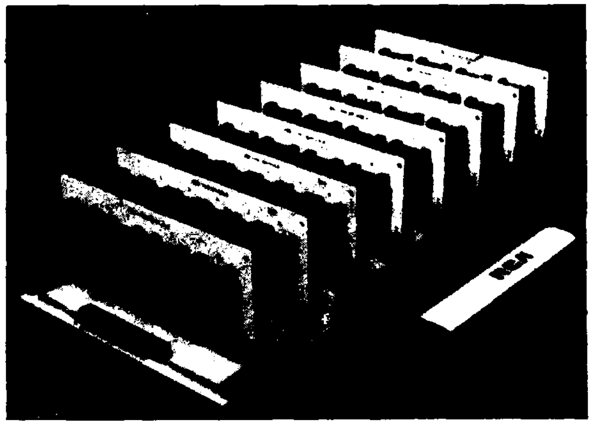

Figure 4. Chip Carrier Burn-In Sockets on Standard Circuit Cards and Frames

Figure 5. Substrate Continuity and Isolation Test Fixtures

ASSEMBLY

Given substrates that are 100% tested, and tested and burned-in active components in the chip carriers, RCA has developed a high-yield assembly operation. A necessary precondition for successful assembly is a solderable metallization system on the substrate and chip carriers, proper design of the chip carrier mounting pads on the substrate, proper amount and type of solder and flux, and a soldering medium that is well controlled and adaptable to various sizes of substrates. Chip carriers are semiautomatically pretinned in 60/40 solder. Solder paste is applied to the substrate. Chip carriers, edge clips, and capacitor and resistor chips (where required) are placed on the tacky solder paste, and then the entire unit is left to dry. The tacky solder paste serves to hold the chips in place during the subsequent soldering. Several soldering systems have been used successfully, including automated hot plates and various types of infrared furnaces. The most successful results to date have been by vapor phase reflow.

The principle of vapor phase soldering is as follows: A fluorinert material is heated in a tank to form a vapor at 215°C; coils at the top of the tank keep the vapors from escaping by recondensing the vapor. Parts to be soldered are placed on a tray that is controllable both in speed of lowering into the vapor and dwell time in the vapor. The vapor gives up its heat of vaporization to the parts by condensing on them; soldering is rapid and is controlled to a maximum temperature of 215°C. Evaluation of this method indicates that the time/temperature of the metallization process is minimum and the best controlled of all soldering systems tested.

Following the assembly operation, final electrical testing is conducted. Experience at RCA indicates a substantially higher yield with this process than with complex single-cavity sealed hybrids (equivalent to printed-circuit board assembly of tested components). In case of chip failure after assembly, repair is a relatively simple matter of heating and removing the chip carrier and replacing the faulty components. Since repair operations do not require unsealing a large hermetic package or working with delicate chips and wire bonds under a microscope, the repair can be accomplished by trained soldering technicians.

MATURITY OF CHIP CARRIERS

The chip carrier has provided the high-density packaging engineer with an alternative to single-cavity hybrids that in many cases equals the conventional hybrid packaging density. It is practical, and has been proven in numerous production applications, to mount and interconnect chip carriers on both sides of a ceramic substrate. Although the chip carrier occupies about twice the area of the single cavity hybrid, when both sides of the substrate are used by chip carriers, the packaging density is equalled. RCA has been using this capability since 1976 when the mirror photograph (Figure 6) was taken of both sides of a sample hybrid. Our production processes have provided excellent yields with standard techniques. The method offers an additional advantage of more easily tailoring the size and shape of the ceramic substrate in comparison to relatively fixed configurations of sealed hermetic hybrid packages. This advantage can now be used to tailor hybrid size and shape with chip carriers on ceramic.

In addition to the wide variety of chip carriers available commercially, an active standardization program has been undertaken with help from DoD: the result is two families of chip carriers suitable for automated production tooling have been approved by the Joint Electron Device Engineering Council (JEDEC). They are produced in 50 mil center-to-center pad dimensions and 40 mil center-to-center dimensions. The JEDEC family designed by RCA under contract to the Air Force is shown in Figure 7. Note that although 40 mil carriers are preferred for minimum size, either 40 or 50 mil center-to-center leads can be used by the hybrid manufacturer. 50 mil center-to-center chip carriers are currently preferred for applications for printed circuit board users because of the match to dimensional standards of 25 mil features and 100 mil spaced holes for printed circuit boards. Both Hughes and Texas Instruments have been funded by DoD for 50-mil center-to-center chip carriers which are standardized by JEDEC.

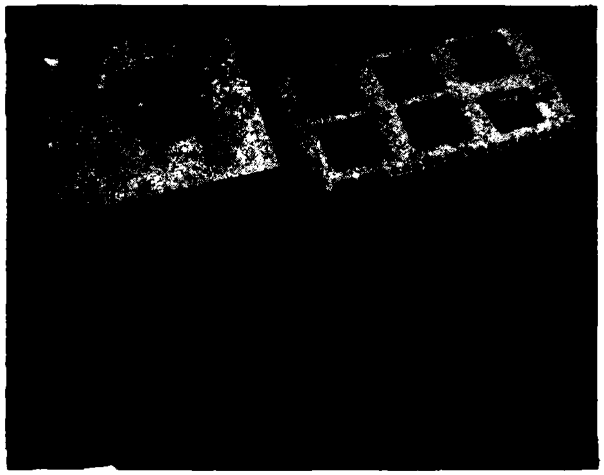

Figure 6. Double Sided Hybrid

APPLICATIONS

Numerous applications have been developed by RCA which have been produced for both commercial and military environments. Typical examples are shown in Figures 8 and 9. Figure 8 shows a double sided Navy "Improved Standard Electric Module" containing 70 chips. Thirty-two 1K memory chips plus four control chips are mounted and interconnected by multilayer thick-film ceramic substrates on each side of the module. Figure 9 shows a high-speed 16-bit microprocessor packaged in the new JEDEC standardized 84-lead chip carriers with high speed multiplier chips in 64-lead chip carriers. Chips in low-power high-speed CMOS/SOS, and module packaging are provided by RCA.

Figure 10 shows an assembly of components in chip carriers, attached and interconnected by multilayer thick film on ceramic, and then interconnected together by a four-layer PCB. Note that one unit is attached directly to the PCB by the same stress relieving pins used to attach the ceramic substrates.

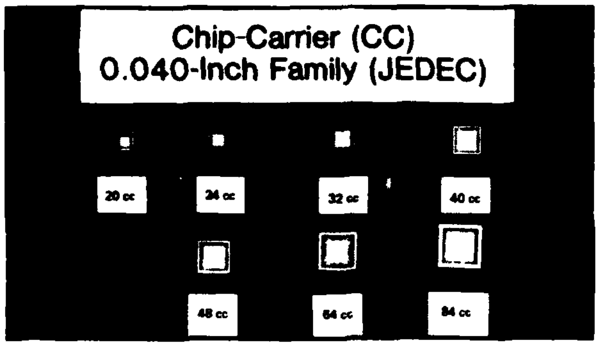

Figure 7. 40 Mil Center-to-Center Family of Chip Carriers Proposed for JEDEC Standardization

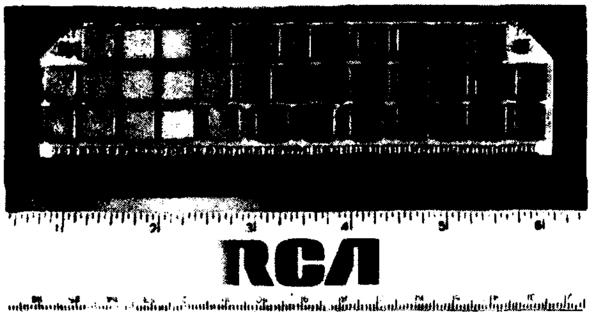

Figure 8. 70-Chip Double-Sided Hybrid (ISEM)

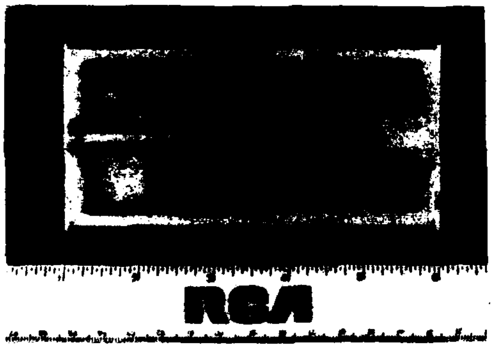

Figure 9. 16-Bit Microprocessor CPU with Hardware Multiplier

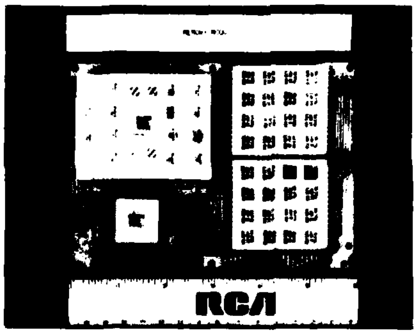

Figure 10. Printed Circuit Board with Groups of Leadless Ceramic Chip Carriers on Ceramic Sub-boards and Leaded Chip Carrier on PCB

CONCLUSIONS

1. LSI and VLSI technology with many I/Os requires a new packaging technology so that the inherent advantages of increased performance and reduced size at the chip level can be realized at the package and module levels.

2. Increased complexity of LSI and VLSI requires complete testing of all I/Os and at temperature limits for high reliability applications.

3. HCCs improve performance by reducing lead capacitance and conductance, reduce size to one fifth, and provide a mechanism for test and handling. In fact, it is possible with HCCs on multilayer ceramic substrates to provide packing densities comparable to conventional "chip and wire" hybrids.

4. HCC maturity has been "accelerated" by DoD investment and industry activity to standardize via JEDEC JC-11.3.1 chip carrier outlines, footprints, and mechanical features for orientation and alignment, and burn-in and test sockets.

5. Techniques have been established and proven for reliable assembly and interconnections on ceramic substrates and, with stress relief, on organic printed circuit boards.

RECOMMENDATIONS

1. Reduced-size chip carriers are indicated for future use of 48 I/O and larger HCCs.

2. Automated module assembly techniques and tooling are required to reduce production module costs.

3. Commercial availability of components in chip carriers is required to increase production and reduce cost.

VALIDATION AND VERIFICATION OF LSI TECHNOLOGIES AND DESIGN TOOLS

C. J. VanLeeuwen, Manager, Reliability
Harris Semiconductor, Products Division

Introduction

At Harris Semiconductor reliability is considered a performance parameter, encompassing both device and process technology, whose time constant is long term. To accomplish this, reliability representation during design and layout reviews of any new product type of new technology is critical and, therefore, mandatory. It is during early phases of new circuit development when employing a new technology, that reliability based layout ground rules are invoked to ensure that reliability is designed and built in rather than only verified after the product technology phases are finalized.

To facilitate timely release of new LSI devices, deploying a brand new process technology, specially designed test vehicles are first constructed to characterize pertinent process parameters. Going one step further in the prove-in phase of a new technology, for example a LSI memory circuit, computer controlled design ground rules are implemented to accommodate computer aided generation of all mask sets using a bit-map topological checking system.

Reliability Prove-in

Central to successful reliability prove-in of our new product lines are the following steps (see Figure 1).

Step 1. Early mandatory reliability interfacing during the design and layout reviews of future circuits with reliability ground rule compliance.

Step 2. Reliability representation and consultation during concept and deployment phases of new process technologies.

Step 3. Reliability representation with qualification requirements as a prerequisite to transfer new product into volume production.

Step 4. Final reliability verification of the first run of a newly transferred product type from volume production. Subsequent reliability qualification will result in release to ship.

The above steps are all equally critical in ensuring that reliability is built in and, at the same time, to safeguard against costly redesign delays.

Before advancing a new technology, our need for specially designed test vehicles is reviewed. If found necessary for reliability characterization of the new process, test vehicles are deployed first before product reliability evaluation commences. (See Figure 2.)

In so doing, the inherent reliability of the new process technology is determined first to avoid potential problems in later stages.

Follow-on In-depth New Technology/Product Characterization

Following familiarization of circuit design, chip layout topography, and product functional operation (deploying a new technology), samples from the first development run are received for reliability evaluation. This evaluation encompasses the following rigorous tests and checks:

1. Stressing devices to destruction by exceeding maximum allowable voltage and temperature to determine failure modes/mechanisms with respect to degree of existing safety margins between applied normal operating stress conditions and absolute maximum ratings. This test provides insight into the inherent weakness of the design and coupled new technology.

2. Determine sensitivity to ESD which is especially critical to MOS and small geometry bipolar components. Sensitivity to ESD is not considered a technology and/or design weakness

as precautionary handling measures are available (see references 1, 2, 3). Also, design techniques can be used to minimize ESD effects.

3. Ensure at the wafer level, prior to the application of passivation, that coverage of metallization over (steep) oxide steps is complete with no "rat-holing" problems.

4. Perform life testing for 1000 hours minimum, dynamic and static, with intermediate variables data read-outs at 168 and 500 hours at nominal V_{CC} (V_{DD}) conditions at 125°C ambient with all failures being analyzed. Acceptance criteria at this state of the evaluation must always be clearly defined. To project high temperature related failure rates to end-use operating conditions, derating by means of the Arrhenius reaction rate is accomplished. This is predicated on process dependent activation energy values (such as 0.3 to 0.6 eV for CMOS/Bipolar -- corrosion, aluminum electromigration, contamination, etc.; 1.00 to 1.15 eV for Bipolar -- surface instability; 1.12 to 1.35 eV for CMOS -- surface instability). The latter are either obtained from the literature or emperically determined.

The additional tests below are more directly product related:

1. Verification of residual moisture content internal to the package by means of the dew point technique using the Harris HIO-55001-6 moisture sensor chip which is periodically calibrated against a reputable mass spectrographic analysis.

2. Thermal impedance evaluation (θj-a and θj-c).

3. Internal visual scrutiny for possible anomalies pre and post stressing which have not progressed far enough to cause malfunction.

4. For epoxy sealed products key tests are:

   - 168-hour autoclave (with no bias).
   - 1000-hour 85°C/85% RH with bias.
   - Temp-cycle.
   - Thermal shock.
   - Continuously monitored temp-cycle to check for intermittency.

5. As a stand-alone procedure, all vendor package types and piece parts are qualified in accordance with rigorous MIL-STD-883B procedures to ensure that thermal and mechanical environmental conditions are met initially and continue during ongoing monitoring programs. This also includes internal particle detection evaluation.

Examples of Process Technology Evaluation

We have learned that when choosing a technology, you have to design a circuit around it to avoid raising a conflicting capability later while trying to match the technology with certain circuit performance parameters. This has resulted in the concept of evaluating process test vehicles.

Specially designed test vehicles and/or expander dice were used to reliability qualify the following new process technologies prior to circuit (device) deployment.

1. Nichrome Fuse Technology for Bipolar PROMs

   When the first (bipolar) PROM in the industry was announced by our company, the 0512-HPROM was introduced deploying nichrome fusible links to program the bit content contained in the memory matrix. Prior to the release of the first PROM, a reliability study was performed to determine the optimum fusing conditions; i.e., programmability, pulse width, fuse geometry with minimum applied voltage, etc., as a requirement to ensure that programmed fuses remain open (and conversely, unprogrammed fuses always remain intact) during end-use operation of the PROM. This study enabled us to

determine the critical circuit parameters afforded in the PROM to accommodate the nichrome fuse as a viable and reliable technology. (Reference 4.)

Elaborating on this, the key to successful reliability prove-in of the nichrome fusible link was the ultimate understanding about the fusing mechanism. After having ruled out the first three (A, B, C) possibilities below, we found that the fusing force obeys the field enhanced ionic mass transport mobility model (D).

A. Electromigration: Mass flux occurs under the influence of high current flow because electron collisions with atoms of the conducting medium provide a net motion vector in the direction of electron flow.

B. Thermal gradient: In the presence of a thermal differential, material will diffuse from the high temperature to the cold temperature region.

C. Concentration gradient: In an imbalanced distribution of concentration to lower concentration.

D. Field enhanced ionic mobility (Reference 5): Molten metals will ionize, lose electrons and become cations. In the presence of an electric field, they will be driven towards the cathode.

A computer thermal analysis program called "THEROS" was used to calculate the dynamic temperature effects in a PROM-fuse structure as a function of applied power density. The expression "power density" is defined as the amount of power that is dissipated in the fuse neck region divided by its cross-sectional area. The concept of defining power density as power per unit surface area is applicable to thin film heat flow problems where the heat is dissipated through a surface. (The concept is analogous to defining current density as current per cross-sectional area.)

With reference to Figure 3, a plot of computer results shows the temperature in the center, narrow neck region, can easily reach the melt temperature of nichrome within microseconds for power densities >2.5 watts/mil^2.

Figure 4 is a plot of the intercept of the time to reach the melt temperature (1450°C) versus the power density. This theoretical prediction of the power density versus time to reach the melt temperatures compares well with experimental data on time to fuse. The data in Figure 4 was taken from the test vehicle fuses (processed identically to circuit fuses, but free of interfacing circuitry). This allowed precise characterization of fuse-pulse interactions. The data matches for long fusing time but deviates for short fusing times. This difference can be accounted for by considering the definition of "time-to-fuse." The experimental data points represent total time to fuse which includes rise time of the programming pulse, time for the fuse to heat to sufficient temperature, and time of the actual fusing event. For example, Figure 5 shows a typical current trace for a fuse programmed under constant voltage conditions. The trace shows a fixed rise time, t_r (about 100 nanoseconds for this data), a response time, t_m, for the nichrome to reach the melt temperature, and a time for the fuse neck to enter the melt phase and program, t_f. Plotting the time defined as t_m shows excellent correlation with the theoretical prediction of the time to reach melt temperature. The difference between the theoretical prediction to reach melt and the actual time to fuse agrees with the measured values of $t_r + t_f$. Figure 4, therefore, shows that fusing follows a heat flow dependence that requires the nichrome to achieve melt. Proper PROM design necessitates taking into account thermal factors that affect the heat

flow conditions in the neighborhood of the fuse. Concentrating power by optimum fuse geometry and ensuring sufficient power to the fuse will achieve fast, uniform programming.

We found that the power density versus time to program curve (Figure 4) is described well by the heat flow model and implies a single mechanism, melting, for fusing both fast and slow programming. Further, high power programming (fast blow) approaches adiabatic heating conditions and therefore gives a large melted region and a wide gap; restricted power programming (slow blow) on the other hand allows much of the heat to diffuse away taking longer for the fuse to reach melt.

We also learned, by grossly violating recommended programming procedures for fuses, that it is possible to create a marginal fuse gap that may be subject to reverting state ("grow-back"). This anomaly was induced in a test vehicle fuse by restricting the power input to a value on the $t \rightarrow \infty$ asymptote (~ 1.5 watts/mil^2) of the power density versus time to fuse curve (see Figure 4). Under these conditions, a fuse was induced to program, become electrically discontinuous, after 5 minutes of sustained power. This effect, programming under anomalously reduced power, was not found to be reproducible. Many fuses at this power density would not program after days. During this study we also found that the fusing phenomenon based on SEM results have been erroneous or misleading because what was seen was an artifact of sample preparation. The technique of using transmission electron microscopy (TEM) to examine a programmed fuse gap (see Figure 6) is the only technique which mutually satisfies the requirements of sufficient resolution to analyze the gap and not destroy in sample preparation the original structure to be analyzed. Also, we found that in depassivating devices, fuse gaps are destroyed.

A deliberately improperly programmed fuse was subsequently subjected to a slowly applied DC voltage ramp under current limited conditions (10M-ohm resistor in series). At 12 volts the fuse resistance dropped to $\sim$5,000 ohms. The TEM photograph of this fuse is shown in Figure 7. It is obvious from this photograph that the reduced power condition has resulted in a fuse that has marginally programmed. That is, the gap created after programming is very narrow (approximately a few hundred angstroms) and subject to a voltage breakdown effect.

Fuses programmed per the recommended power levels will program rapidly with a wide gap in agreement with the mass transport fusing model. These fuses can be subjected to more than 100 volts and will undergo no change in electrical or physical condition.

Additionally, as in Figure 7, if a restricted amount of power is applied to a fuse, it is possible to create a very narrow gap. Under the presence of high voltage and extreme current limiting, it is then possible to force a voltage breakdown across the gap. It is postulated that this voltage discharge results in the establishment of a low conductivity relink at one or a few points of closest approach in the marginally blown gap. This specific structure could not be confirmed with the TEM study because even the TEM did not have the resolution to examine microstructures at <300 angstroms.

2. <u>On-board MOS Capacitors for Linear Devices</u>

MOS capacitors were reliability qualified as stand-alone components with respect to time-temperature applied voltage exposure and maximum voltage surge to check susceptibility. Final reliability prove-in, which also allowed us to tighten critical process controls (e.g., dielectric oxide integrity), led to the successful deployment of the MOS capacitor in linear operational amplifiers such as the HA-2600, 2620, etc.

3. <u>Polysilicon Fuse Technology for CMOS PROMs</u>

When the polysilicon fuse technology emerged, as another viable programmable fuse technology, several years after the nichrome fusible link PROM made its successful debut, aspects similar to the nichrome fuse technology were visioned. Considerable advantage was taken of the compatibility of our company's SAJI CMOS RAM/ROM process. SEM examinations were also made to correlate with the electrical results which clearly showed that programmed and unprogrammed fuses are reliabile with no latent problems. Tightning of critical process controls was found necessary which led to improved programmability yields. It should be mentioned that the test fuses of each CMOS PROM are 100% programmed at final test (as is the case in nichrome fuse bipolar PROMs). This also includes 100% testing the corresponding test rows and columns. This provides the ultimate assurance that the user does not have to fear marginal programming due to residual undetectable process flaws.

4. <u>Via Contact Technology to Link Multi-level Metallization Systems</u>

With the advent of reduced die size, complex IC chips had to resort to the use of a multi-level metallization process requiring a reliable level-to-level interconnect system. To understand this critical connection, special via test vehicles were designed and produced to undergo subsequent reliability qualification. (Reference 6)

Pertinent results of the reliability prove-in of the via contact technology were as follows. Two specially designed two-level aluminum metallization test structures were deployed. Each structure contained fifty via contacts, one being the 0.25-mil via, and the other the 0.50-mil via. Both were incorporated on a single silicon chip. Figure 8 represents a close-up view of a typical level-to-level via contact structure showing the first and second level metal being interconnected by a via contact in an interwoven fashion, thus forming a complete chain of fifty via contacts connected electrically in series. Figure 9 is a cross-sectional diagram of the passivated two-level metal test structure showing the via contacts. (The unpassivated via contact vehicle has no protective SiO_2 over the second level aluminum metallization.) The aluminum thin film cross-sectional area measures typically $4.25 \times 10^{-7} cm^2$. For testing, the chips containing the two test structures, were mounted, wire bonded and sealed in a 4-lead TO-5 package.

In executing the applied stress evaluation program we learned that the 0.50-mil via contacts were better by $1 \times 10^5 A/cm^2$ in stress attainability. Interesting SEM observations were made during a step-stress test as can be noted in Figure 10.

Stable current stressing was provided by means of a constant current source with consistent polarity during all tests. Figure 11 shows the step-stress results. Failure incidence is defined as electrical discontinuity anywhere along the chain of the fifty via contacts per test vehicle. As can be noted, the 50% failure point of passivated via contacts (0.25-mil and 0.50-mil vias combined) occurred at a current density of about $12 \times 10^5 A/cm^2$ as opposed to about $9 \times 10^5 A/cm^2$ for via contacts with unpassivated second level metal. This difference is indicative of improved reliability performance of passivated via contacts. In addition, the 0.50-mil via contacts were better by $1 \times 10^5 A/cm^2$ in stress attainability at the 50% failure point than the 0.25-mil via. Close examination of the failures by means of the SEM showed evidence of electromigration with formation of hillocks and voids in opposing via contact pairs as shown in Figure 10. This failure phenomenon was consistent during both step-stress and constant accelerated

stress testing. No other failure modes occurred.

To predict useful life of the 0.25-mil via contact two-level metal system, three randomly selected samples of ten vehicles were stressed at different accelerated current densities: 7.05 x 10^5A/cm^2, 6.47 x 10^5A/cm^2, and 4.47 x 10^5A/cm^2. In each case, the ambient temperature was maintained at +125°C. The resulting plot in Figure 12 shows the projection to in-use conditions of the 50% failure data as generated by the three sample failure distributions. A log-normal failure behavior was noted for each of these distributions. The common failure mode was electromigration showing alternate void and hillock formation in the via contacts resulting in electrical discontinuity. At a typical in-use current density condition of 1 x 10^5A/cm^2 for M/LSI circuits, employing two-level metallization via contacts, the plot shows an estimated mean time to failure in the order of 7,000 hours. This was unsatisfactory and 0.25-mil aluminum via contacts were therefore not considered for circuit application. Similar data for the 0.50-mil via contact vehicle resulted in 85,000 hours of extrapolated mean life.

5. ESD, EOS and Latch-up Sensitivity

Although ESD (Electrostatic discharge) and overvoltage conditions are not considered inherent device reliability problems, they play an important part in choosing a new technology as it applies to new circuit development. For example, ESD and latch-up sensitivity are not specified as guaranteed parameters, yet they can make the difference in customer acceptance. The particular characteristics of immunity to ESD and latch-up must be designed in. This requires evaluation of test vehicles reflecting the ground rules which would enhance the above immunity, in lieu of using the end-product as an evaluation vehicle. Here especially exist the danger of overlooking the growing tendency to sacrifice reliability safety margins for topographic densification by lessening spacings and routings for electrical charge to achieve faster (AC) performance, thus compelling to push the limits of a technology.

6. Alpha Particle Sensitivity

There exists a general awareness about alpha particle sensitivity in that it can affect memory bit integrity among MOS devices. An extensive internal study and an industry-wide fact finding literature search was made from which conclusions were drawn that CMOS is the least sensitive to the problem.

7. V_T Expander Dice

Relevant to V_T evaluation, a new technology expander die allows monitoring permissible drift under applied stress conditions. To meet high temperature stability depends on how well we can control a process with respect to locking out contamination with no loss in yields.

As an integral part of reliability qualifying new process technologies and new complex ICs utilizing these technologies, extensive use is made of the bit-map checking system at Harris.

The bit-map topological checking system for processing IC mask sets covers all geometric topographic circuit layout aspects (polygons) as it relates to the diffusions, multilevel metallization (polysilicon and aluminum), passivation, etc. This applies to any IC technology of varied complexity. This system can check component densification and in so doing obey earlier programmed reliability oriented design ground rules. Any ground rule violation is readily detectable.

Figure 13 illustrates our typical basic bit-map setup in functional block diagram format.

Typical polygon operators are:

- contains
- contained

- touch
- inside touch
- *outside touch*
- overlap
- coincide
- disjoint
- fill

All these allow control of geometric process/circuit topologic coordination.

What Has Been Learned

The foregoing approach to the reliability qualification of new technologies has provided us with experience from which the following key recommendations can be made:

1. Utilize test vehicles to qualify new process technology.

2. Implement reliability based ground rules from design on out to ensure reliability is built in.

3. Determine how a LSI circuit fails via overstressing in relation to possible process technology weaknesses.

4. Perform defect analysis on fallout from wafer probe and final test to enhance yields by eliminating defect incidence.

The above approach has been adopted in our reliability procedures as a routine matter and by proving in, for example, new technologies as referred to earlier, the following conclusions are drawn:

1. Stressing product to destruction has always allowed us insight into basic strength and weaknesses of a technology.

2. Defect analysis for yield enhancement purposes has shown us where to tighten the controls in the process flow as well as what latent problems to expect later in the field if we would not make corrections.

3. Implementation of reliability ground rules has always paid off dividends in that costly redesigns were avoided with reliability pay-back.

What's Ahead

What's ahead is actually already here when the advanced failure analysis section of the reliability department at our company performs routinely in-depth defect diagnosis, with the aid of sophisticated analytical apparatus such as SEM, SAM and SIMS, electron microprobe, etc., on wafer probe and final test IC fallout. This is in support of yield enhancement for the various product engineering groups. What this also provides is important feedback to the new technology groups. This is in terms of intolerable material defect levels, possible process induced contamination and flaws with emphasis on the associated latent character as it can adversely affect future technologies. It will also lead to the further refinement of the analytical tools and methods to rapidly perform defect diagnosis on state-of-the-art technologies and their highly complex large scale IC derivatives. At Harris we intend to continue to face that challenge of coupling sophisticated evaluation procedures with diagnostic means and computer-aided methods to cover ICs of ever increasing density and complexity employing advanced high technologies.

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3. Handling rules contained in pages 5-8 of the Harris Bipolar and CMOS Digital Product Catalog.

4. Davidson, J. L.; Gibson, J. D.; Harris, S. A.; "Fusing Mechanism of Nichrome Thin Films," presented at the 1976 International Reliability Physics Symposium.

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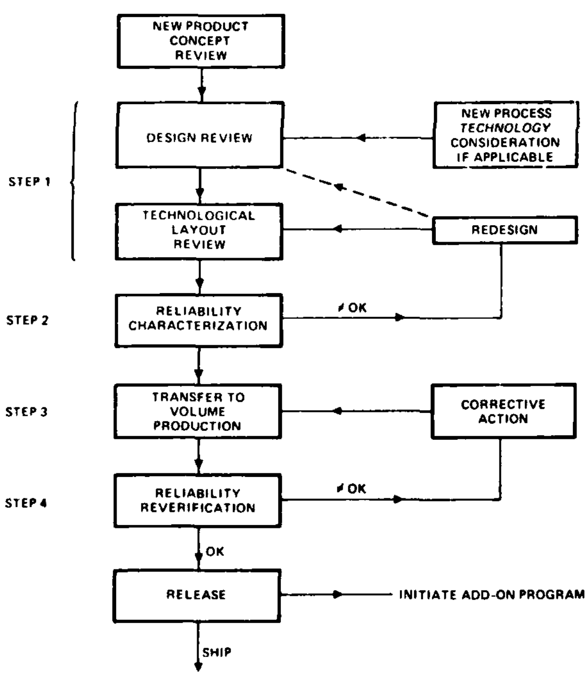
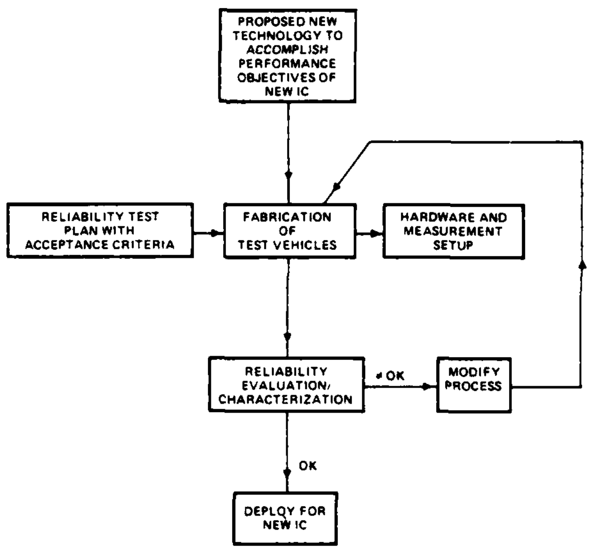
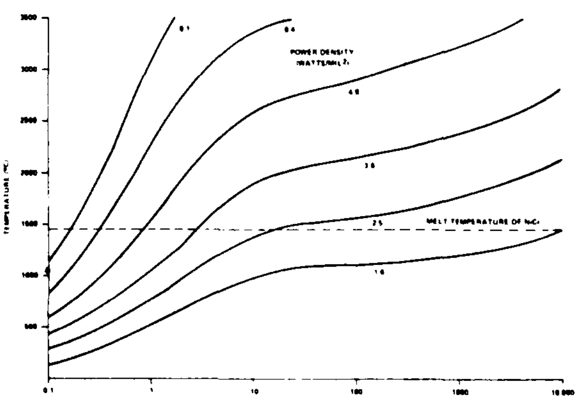
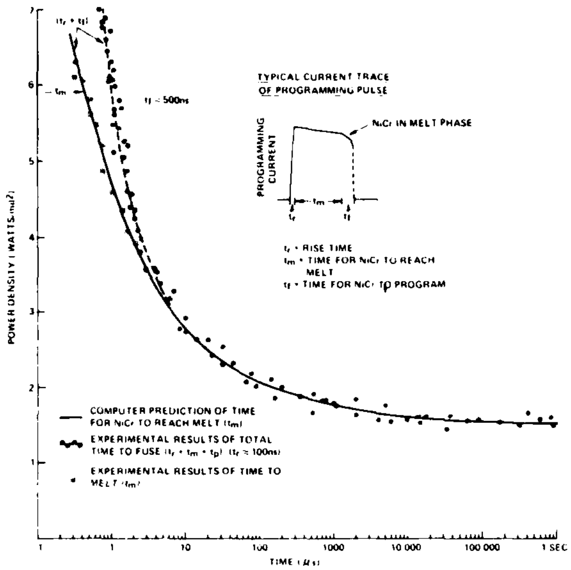




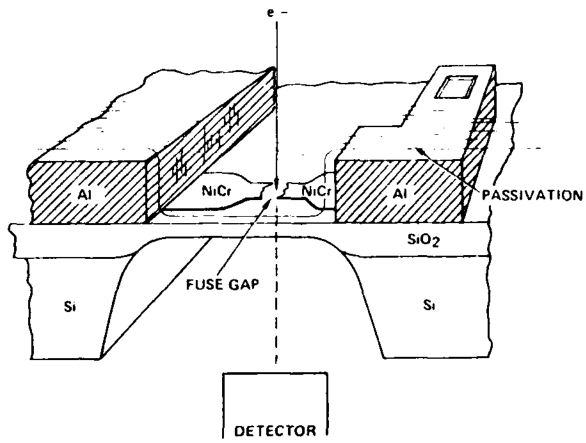
DYNAMIC HEATING OF NiCr FUSE VS. POWER DENSITY



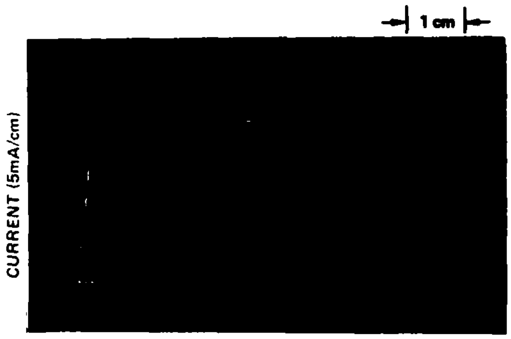
POWER DENSITY VS. TIME TO FUSE



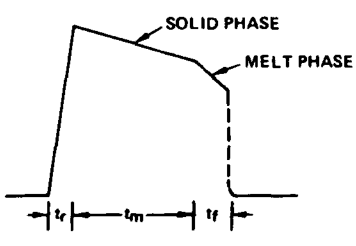
SCANNING TRANSMISSION ELECTRON MICROSCOPY ANALYSIS OF FUSES



PROGRAMMING PULSE CHARACTERISTICS



TIME (500ns/cm)



t_r = RISE TIME OF PROGRAMMING PULSE

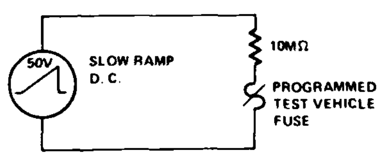
t_m = TIME FOR NiCr TO REACH MELT

t_f = TIME OF THE FUSING EVENT (IONIC MASS TRANSPORT)

MARGINALLY PROGRAMMED TEST VEHICLE FUSE

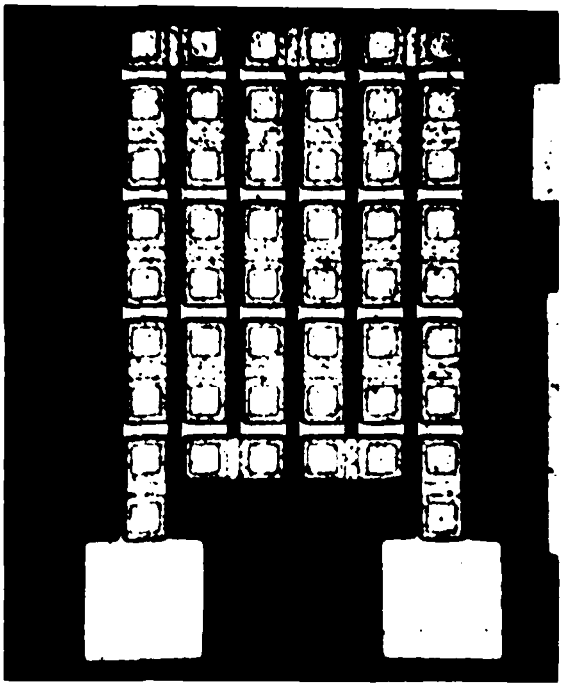
PROGRAMMING CONDITIONS:
POWER DENSITY = 1.5 WATTS/MIL^2
TIME TO FUSE = 300 SEC.

FORCED RELINK OF MARGINALLY PROGRAMMED TEST FUSE



AT 12 VOLTS,
R_F DROPPED TO $\simeq$ 5KΩ

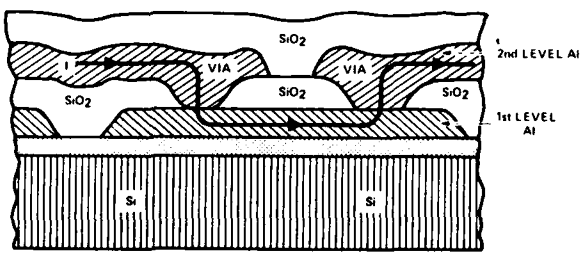
0.50MIL VIA CONTACT SERIES



PASSIVATED

TWO-LEVEL VIA CONTACT TEST VEHICLE

(CROSS-SECTIONAL VIEW)

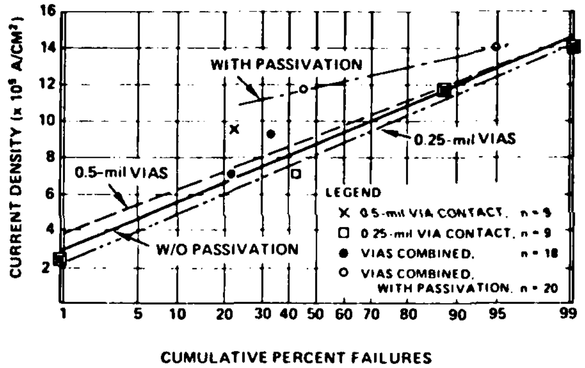


SCANNING ELECTRON MICROSCOPE PHOTOMICROGRAPH OF 0.50MIL VIA CONTACTS

FOLLOWING STEP STRESSING FIRST LEVEL MODEL EXHIBITING ELECTROMIGRATION EFFECTS CAUSING CATASTROPHIC FAILURE INCIDENCE

CURRENT STEP STRESS PLOT

@ T_A = +150°C



STEP STRESS SCHEDULE

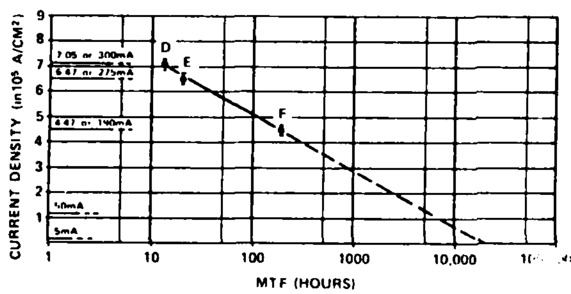
APPLIED CURRENT DENSITY (in 10^5 A/CM^2)		CUMULATIVE TIME (IN HOURS)
2.35	(100mA)	24
4.70	(200mA)	48
7.05	(300mA)	72
9.40	(400mA)	96
11.75	(500mA)	120
14.10	(600mA)	144

CONSTANT ACCELERATED STRESS IN TIME PLOT

@ T_A = +125°C
0.25 mil VIA CONTACTS (UNPASSIVATED)

@ CURRENT DENSITIES:

D. 7.05×10^5 A/CM^2
E. 6.47×10^5 A/CM^2
F. 4.47×10^5 A/CM^2



GALILEO ORBITER COMMAND AND DATA SUBSYSTEM

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General

The 1984 launch Galileo mission consists of two separate shuttle launches, the probe with carrier and the orbiter. The galileo orbiter is to some extent an evolution of previous Jet Propulsion Laboratory spacecraft except for marked differences such as three axis stabilization versus a dual spinner. Another difference is the Command and Data Subsystem (CDS). This subsystem evolved from the combination of two special purpose central computers, the Computer Command Subsystem and the Flight Data Subsystem. Its tasks include decoding uplink command messages, storage and execution of timed commands, collection and formatting of downlink telemetry, and the detection and correction of spacecraft errors.

In order to obtain a better understanding of the CDS design one must understand its role on the spacecraft. Figure 1 is a CDS view of the spacecraft and how the other subsystems and systems interact with it. As can be seen in the figure, the uplinked data passes through the S/X Band Antenna Subsystem, Radio Frequency Subsystem, and Modulation Demodulation Subsystem, arriving at the CDS as an NRZ binary data stream. It is the CDS task to synchronize to the data, extract the command information, and initiate the decoded response. That response can consist of passing a subset of the data to another subsystem as a command, executing the command if it is for the CDS, or storing the data for future evaluation if it is a stored sequence. Stored sequences take the form of time-event tables which are stored temporarily in the CDS until a specified future time is realized. The events are then interpreted and can range from simple commands to the CDS or other subsystems, to more complex sequence expansions which consist of parameterized routine calls. Those routines can cause commands to be issued or initiate other stored sequences.

Besides serving as the central command distributor, the CDS is also responsible for data collection, evaluation, formatting, and routing. The collected data consists of subsystem and system status information, science observation data, support engineering data, and memory readout data. Most of this data is collected, formatted, and routed to the telemetry output data ports to be recorded or downlinked from the spacecraft. Some of this data, however is examined by the CDS in order to evaluate the spacecraft performance and state. Improper performance or erroneous states are generally handled by initiating correction responses which consist of previously stored time-event tables.

Besides the command and data handling functions, the CDS serves as the central spacecraft timing source and clock. The clock information is distributed to those subsystems needing it via the command and data bus. This bus represents the central communication path between the distributed processors of the various subsystems and it is the CDS responsibility to maintain the agreed-upon bus protocol. It is also the CDS responsibility to provide a block redundant design for long life reliability and the ability to actively use that redundancy to provide single fault tolerance during critical mission phases.

Hardware Description

The architecture of the CDS is based on a distributed approach developed at the Jet Propulsion Laboratory under NASA Contract NAS 7-100.[1] This architecture was selected to take advantage of the new microprocessor technology and to also serve as the core of the anticipated distributed microprocessor driven spacecraft. The design selected was a distributed microprocessor system interconnected by a high speed data bus which is extended to interface with the other microprocessor

[1] The Unified Data System: A distributed Processing Network for Control and Data Handling on a spacecraft. Proc. IEEE National Aerospace and Electronics Conference, NAECON, Dayton, Ohio, May 1976 (Rennels, D. A., Riis Vestergaard, B., and Tyree, V. C.)

[2] RCA 1802 Microprocessor: User Manual for the CDP1802 COSMAC Microprocessor (MPM-201B)

driven subsystems. The extension of this bus provides the primary communications path between the CDS and the other subsystems/instruments. As the Orbiter consists of a spun and despun section, this extension must pass through the spin bearing assembly to link the spacecraft sections together.

Figure 2 is a functional representation of the spun and despun sections of the CDS. A brief discussion of the illustrated elements follows:

1. Hardware Command Decoder (HCD). This is the basic communication path to the CDS and the spacecraft from the ground. A serial bit stream is decoded and routed to the designated CDS element or Orbiter subsystem.

2. Critical Controller (CRC). There is a redundant pair in both CDS sections serving as the "lock and key" to protect critical functions, random writing in memory, and establish the configuration of the CDS. It may be accessed by the Hardware Command Decoder or by the CDS High Level Modules under special conditions.

3. High Level Modules (HLM). Each contains an RCA 1802 microprocessor[2] operated at a clock frequency of 1.6128 mHz with 32K Read Write Memory (RWM) consisting of eight bit words with error detection parity. The 32K RWM is "write-protected" in 4K blocks. In addition, each High Level Module contains a Bus Adaptor (BA) which shares a complete "off-chip" Direct Memory Access (DMA) function allowing the bus system to enter or extract data from the memory. Each High Level Module also has a bus controller which, like the BA, is dedicated to its bus. The BC, which is unique to High Level Modules, can move blocks of data between memories of all modules, connected to its bus. The bus controller, operating independently from the microprocessor, reads a control table directly from the memory to specify the bus transfers.

4. Low Level Modules (LLM). Each contains an RCA 1802 microprocessor operated at a clock frequency of 1.6128 mHz and 16K RWM. In addition, each Low Level Module contains a BA, which can be assigned to any bus by the critical controller and extensive engineering input/output (I/O). That I/O includes digital command buffers, discrete command buffers, analog (includes temperature) inputs, bi-level inputs, serial digital inputs, and a low rate telemetry output.

5. Bulk Memories (BUM). Each contains 16K RWM and two BAs which can individually be assigned to any bus by the critical controllers. Also, each Bulk Memory contains a telemetry output and format interface which can be outputted to the downlink at rates up to 115.2 kbps.

6. Data Memory Bulk Memories (DBUM). Each contains 8K RWM and a BA which can be assigned to any bus. Additionally, there are interfaces for inputting high rate data and outputting and formatting tape recorder high rate data.

7. Golay Coders (GC). Provide the capability to encode 432 bits of data using Golay (24,12) code with an interleaved depth of 36. The Golay Coder BA can be assigned to either bus.

8. Multiplexers (MUX). Under the control of the bus systems, a reply data input (R) is selected from the internal and external bus users and routed to the Command and Data "Supervisory" bus.

9. Timing Chains (TC). Provide the basic timing internal to the CDS and to the external bus users. The basic Orbiter time is the distributed Real-Time-Interrupt which is 66-2/3 milliseconds. Elements internal to the CDS are given the 1.6128 mHz clock and RTI. External users are given RTI and 806.4 kHz from which they derive bit and word sync for bus communication. Distribution of this timing is phase lock looped to insure operation through transients.

10. Command and Data Bus (CDB). Contains three (3) dedicated busses. Two are individually controlled by the dedicated BC of a High Level Module. The third is controlled by the CDS support

equipment during initial memory loading and not used otherwise.

The purpose of the CDB is to transfer data from one memory to another. All commanding, memory loading, and data collecting are implemented through this mechanism.

A typical data path consists of the bus controller which manages the bus transaction, the single bus adaptor which is selected as a data source, and the one or more bus adaptors which are selected as data recipients. Bus controller instructions are passed over the "supervisory" bus at a 403.2 kbps rate to the bus adaptors. The reply data is passed over a reply line after having been selected as one signal path out of many by the multiplexer. This allows the controller to retain management of traffic on the supervisory data bus which is the data distribution path.

11. Power Converters (PC). The redundant power converters can each supply power for the entire CDS. As indicated, the CDS despun section power is supplied from the CDS spun section power converters through the spin bearing assembly.

The CDS flight configuration is shown in Figure 3. The Command and Data Bus controlled by the HLM 1A is considered the prime data bus while the bus controlled by HLM 1B is the back-up. The prime data bus services the interfaces with all external bus users and is also used to collect and format the high data rate telemetry. During noncritical mission phases the HLM 1A bus will be generally used in a single string mode of operation with the HLM 1B bus serving as back-up. The HLM 1B bus will serve an active role during all critical mission phases by issuing the mission critical commands through its own set of redundant interfaces (mainly through LLM 1B and LLM 2B). In the event of a failure the two data bus roles can be interchanged, with the HLM 1B bus serving as the prime data bus.

Software Description

The CDS software functions are distributed amongst the various elements as indicated in Figure 4. Although the HLMs and LLMs are the only elements which contain a processor, the BUMs and DBUMs are included because they contain memory which is managed as software. The software elements can be described briefly as follows:

1. High Level Modules (HLM) - The HLM serves as the only direct software recipient of command data. Some of that data is meant for the HLM and is either decoded as a processor command and executed, moved as memory or sequence storage data, or temporarily stored in memory to be interpreted as command data at a future, specified time. Data which is not meant for the HLM can be memory data or commands which are moved to the appropriate elements either internal or external to the CDS via the Command and Data Bus.

   The Command and Data Bus is also used to distribute the spacecraft clock which is maintained by the HLM software and used to coordinate all spacecraft activities. Besides serving as the driver for the temporarily stored command data, the spacecraft clock is also used by the HLM software for the execution of stored sequences. That data is in the form of time-event tables which are time-ordered according to an absolute or relative clock. At the appropriate times the events are interpreted as command data and the corresponding actions taken. Besides the simple actions previous described and called events, more complex actions, called pseudo-events can be taken. These pseudo-events are parameterized routine calls which initiate algorithms causing subsequent activities. Frequently these activities result in the creation of a large number of commands and the process has become known as sequence expansion.

   Besides the uplink commands and stored sequences, another source of spacecraft commands is the HLM alarm monitoring function. This function, controlled by the HLM software,

monitors status and performance data which is either directly available to the HLM or is made available through the command and data bus. That data is compared against anticipated performance and spacecraft states and any deviations result in the initiation of an error recovery process, frequently consisting of activating a previously stored time-event table which generates corrective commands.

As can be seen, the HLM software is the source of all spacecraft commands which are either executed internally by the HLM or distributed to the spacecraft via the command and data bus. This bus, which is controlled by the HLM software, is also used to control all data movement on board the spacecraft. That data is used for alarm monitoring, downlink or record telemetry, or memory readout. Alarm monitor data must be moved to the HLM for processing. Downlink telemetry and memory readout data must be moved to the BUM for formatting while the same data must be moved to the DBUM to be formatted for recording.

2. Low Level Modules (LLM) - The LLM software is subservient to the HLM software and interfaces with it through the command and data bus. Although the LLM maintains time for synchronization, it will resync if there is a difference between its time and the time distributed by the HLM. All LLM commands are received from the HLM and either executed internally as LLM processor commands or queued and subsequently issued to other subsystems as discrete (relay closure) or digital (serial binary data stream) commands. The LLM software is also responsible for the collection of status information from itself and those subsystems which interface directly with the LLM rather than with the command and data bus. Although the status collection is table driven it represents a large task for the LLM because the data must be subcommutated and properly "packetized" for collection by the HLM bus. The HLM bus also routes the low rate telemetry to the LLM where it is buffered prior to being sent down to the ground.

3. Bulk Memories (BUM) - The BUM "software" interfaces with the other software elements via the HLM bus. Its memory capacity is used to store error recovery algorithms not frequently required by the HLM and stored sequences. Its memory also contains buffers for telemetry information which is formatted and output over the high rate downlink telemetry channel, and buffers which are used for interbus communication.

4. Data Memory Bulk Memories (DBUM) - The DBUM "software" also interfaces with the other software elements via the HLM bus. Its memory contains buffers for telemetry information which is formatted and output to the tape recorder (Data Memory Subsystem) and buffers which are used for the high rate solid state imaging (SSI), plasma wave subsystem (PWS), and playback input data.

The basic microprocessor software structure (HLM and LLM) is shown in Figure 5. The foreground executive is driven by the hardware's real time interrupt (RTI) which occurs once each 66-2/3 msec. This exec handles timekeeping and the hardware software coordination which is done at the RTI level. It also passes control to the background executive which works on a ten RTI basis and is responsible for all the other software functions which are summarized in the figure.

Hardware/Software Interface

The hardware and software interface occurs, in time, at the RTI level. The hardware is responsible for all timing finer than an RTI while the software is responsible for all timing coarser than an RTI. Hardware activities, established by the software during an RTI interval, are activated on the next RTI. This keeps the hardware-software synchronization at an RTI level and eliminates any fine timing interactions. This principle is illustrated in Figure 6. The software functions start with the RTI driven spacecraft clock followed by the 10 RTI driven functions. Some of the hardware functions, all driven by RTI, are also illustrated.

The hardware is controlled by the software through writing in out-of-range memory addresses (memory mapped I/O) and through direct memory accessed (DMA) tables when

timing finer than an RTI is required. The software attains status information from the hardware through reading out-of-range memory addresses (also memory mapped I/O) and from DMA tables when timing finer than an RTI is required. To illustrate these points the six examples of Figure 6 are discussed.

1. Bus Control

   a) The address of the bus control table is written into an out-of-range address.

   b) At the next RTI the table is read out of memory by the bus controller and used to transfer data between memories connected to the bus. The reading of the bus control table, the reading of memory, and the writing of memory are all through DMA.

2. Status/Telemetry

   a) The address of the channel identifier table (and consequently the input data table) is written into an out-of-range address.

   b) At the next RTI the words in the channel identifier table are individually read from memory, the identified channel is sampled, and the input data is individually written into memory. The read and write memory processes are both DMA.

3. Telemetry Out

   a) The address of the telemetry formatter table is written into an out-of-range address.

   b) At the next RTI four words of the telemetry formatter table are read out of memory to establish the address of the first data block and the number of words it contains.

   c) On the same RTI, immediately after b), the first data block is read out and sent down telemetry by the telemetry sequencer.

   d) At the conclusion of c) the next four words of the telemetry formatter are read out of memory to establish the address of the next data block and the number of words it contains.

   e) Immediately after d), the next data block is read out and sent down telemetry by the telemetry sequencer.

   f) Items d) and e) are repeated indefinitely until reinitialized by item a).

4. Record Data Out

   a) Fundamentally this is the same process as Telemetry Out.

5. Hi Rate Data In

   a) The address of the Hi Rate Data In buffer is written into an out-of-range address.

   b) At the next RTI subsequent incoming data words are stored consecutively in the Hi Rate Data buffer starting at the beginning address.

6. Digital/Discrete Commands

   a) The two bytes of command data (digital or discrete) are written into an out-of-range address.

   b) At the next RTI the command execution process is initiated. (It requires 2 RTIs for completion.)

Command and Data Bus

The heart of the spacecraft communications is the command and data bus. This bus serves as the major link between the various elements of the CDS, the CDS and the majority of the spacecraft subsystems, and the spun and despun sections of the spacecraft. Subsystems which do not interface directly with the bus, interface with the low level modules which make the subsystem unique interfaces compatible with the bus.

The format of the bus is shown in Figure 7. The header portion contains control information consisting of groups of 3 words followed by a final word. Each 3-word group identifies a user, whether the user

is to be a source or recipient, and a 16-bit address in memory for the beginning of the data transfer. Although multiple recipients are allowed, only one source is permitted. The final word, called the number-of-words word, tells the bus controller how many data bytes are to be transferred and informs the participants that the transfer is about to begin. The transfer consists of 0-to-127 words of data (sometimes the address information is the message) and it is terminated by the bus controller starting another bus transaction. In those cases where there are no more transactions scheduled the bus controller puts out a filler pattern which also serves to terminate the preceding transaction. The filler pattern continues until more transactions are initiated at the next RTI. These transactions are in reality memory-to-memory transfers used to distribute and collect data. The distributed data is typically command or memory load information while the collected data is usually telemetry, monitor, or memory readout data.

Recognizing that the bus is really a communication path between distributed memories and that most of these memories have multiple DMAs, one can envision the CDS and its external bus users as an interconnection of multiport memories. An example of this concept is shown in Figure 8. While this figure does not represent all of the external bus users or the CDS it does give insight into the basic concept. Allocating the basic functions described in the hardware/software interface section to Figure 8 can be done as follows:

1. Bus Control

    a) The Bus Controller is shown as the right block in the High Level Module.

    b) The bus adapters are shown as the bottom blocks in the top elements and the top blocks in the bottom elements.

    c) The Bulk Memory has a second bus adapter shown as its right block which interfaces with the other command and data bus.

2. Status/Telemetry In

    a) This is the bottom block on the right in the Low Level Module.

3. Telemetry Data Out

    a) The telemetry formatter is shown as the left block in the Bulk Memory.

    b) The telemetry sequencer is shown as the bottom block in the Bulk Memory.

4. Record Data Out

    a) This is similar to the Telemetry Data Out except the blocks reside in the Data Memory Bulk Memory.

5. Hi Rate Data In

    a) This is the right block in the Data Memory Bulk Memory.

6. Digital/Discrete Commands

    a) This is the bottom block on the left side in the Low Level Module.

A few examples help illustrate the concept. Uplink data arrives at the Hardware Command Decoder where it is initially decoded and passed on to the High Level Module through the command interface DMA. Periodically the HLM 1802 microprocessor checks for the presence of command data in order to further decode it. If that data is not for the HLM it schedules a future bus transaction to move it to the appropriate recipient. If the data was a bus command the activity would be concluded with the bus transaction. If, however, the data was a digital or discrete command it would be passed to the Low Level Module. The LLM 1802 microprocessor which periodically checks for the presence of command data would find the digital or discrete command and place it in a queue for execution. As the LLM 1802 microprocessor advanced the queue it would eventually get to the subject discrete or digital command and place it in the out-of-range memory addresses for activation. On the next RTI the hardware would issue the relay closure or send the binary serial data to the appropriate user and the activity would be concluded.

Another example would be the processing of engineering telemetry status. This data is available through interfaces with the Low Level Module. The request for that data plus others is loaded into a table according to a previously specified schedule. The engineering status hardware reads the request, samples the data, and stores the result into the data table. The LLM 1802 will then take the information from the data tables and "packetize" it into concurrent memory locations for pickup by the bus. During the specified RTI, that data is moved from the LLM and other engineering telemetry sources to build a larger telemetry collection in the Bulk Memory. From there that information is picked up by the telemetry sequencer under directions from the telemetry formatter and the data is sent down the downlink.

Summary of CDS Characteristics

1. Distributed architecture based on high-level and low-level modules. The core of these modules is the RCA 1802 microprocessor and the high capacity bus adaptors and controllers. 1802 characteristics are:

   a) Radiation-hardened CMOS technology

   b) 95 op codes (register oriented)

   c) Operated at 1.6128 mHz yielding approximately 5 microseconds per cycle. Most computational operations are two machine cycles.

   d) DMA capability

2. Utilizes CMOS technology throughout

3. Planar (high-density) packaging on multilayer boards mounted on honeycomb structure.

4. Estimated power: 30 watts

5. Estimated weight: 30 Kgm

6. Estimated volume: 3000 in^3

7. Six RCA 1802 microprocessors.

8. Software basically table driven under the control of executive structure.

9. 176K bytes of storage in 10 memories

10. Supervisory Bus Rate: 403.2 kbps

11. Downlink Telemetry: 115.2 kbps maximum

12. RTI: 66-2/3 milliseconds

13. Maximum Record Data Rate: 806.4 kbps

This paper presents the results of one phase of research performed at the Jet Propulsion Laboratory, California, California Institute of Technology, sponsored by the National Aeronautics & Space Administration under Contract NAS 7-100.

SPACECRAFT BLOCK DIAGRAM

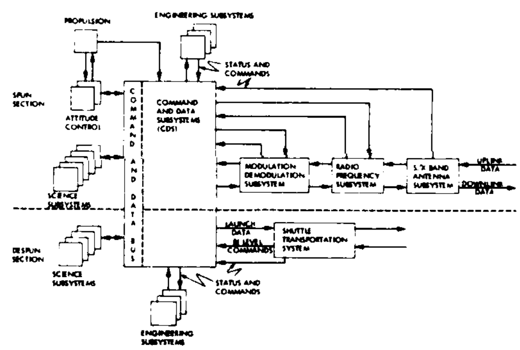


Figure 1

CDS HARDWARE BLOCK DIAGRAM

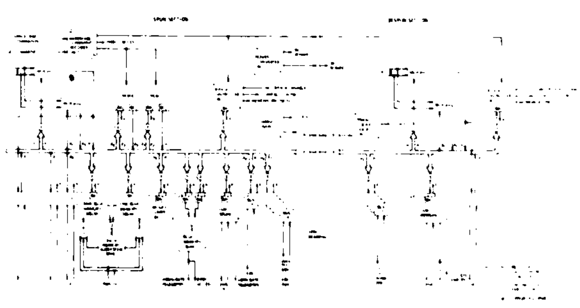


Figure 2

CDS FLIGHT CONFIGURATION

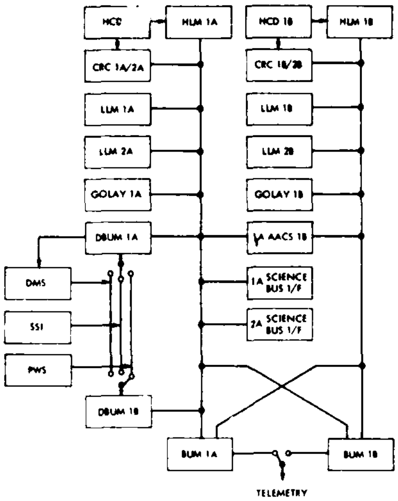


Figure 3

SOFTWARE FUNCTIONAL ALLOCATION

HLM (1 OF 2)

- UPLINK COMMAND PROCESSING
- SPACECRAFT CLOCK
- STORED SEQUENCE CONTROL
- BUS TRANSACTION CONTROL
- PROCESSOR COMMAND EXECUTION
- TELEMETRY CONTROL
- ERROR RECOVERY CONTROL

LLM (1 OF 4)

- TIMEKEEPING AND RESYNC
- PROCESSOR COMMAND EXECUTION
- DIGITAL COMMAND EXECUTION
- DISCRETE COMMAND EXECUTION
- STATUS/TELEMETRY IN CONTROL
- LOW RATE TELEMETRY BUFFERS

BUM (1 OF 2)

- SEQUENCE STORAGE
- ERROR ALGORITHMS
- TELEMETRY BUFFERS
- INTERBUS TRANSFER BUFFERS

DBUM (1 OF 2)

- RECORD OUTPUT BUFFERS
- SSI, PWS AND PLAYBACK INPUT BUFFERS

Figure 4

SOFTWARE FUNCTIONAL BLOCK DIAGRAM

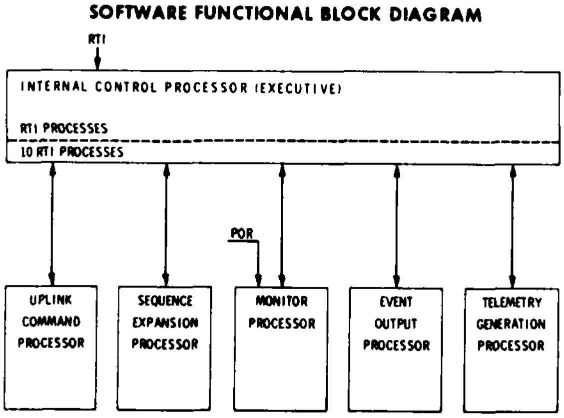


Figure 5

HARDWARE/SOFTWARE INTERACTION

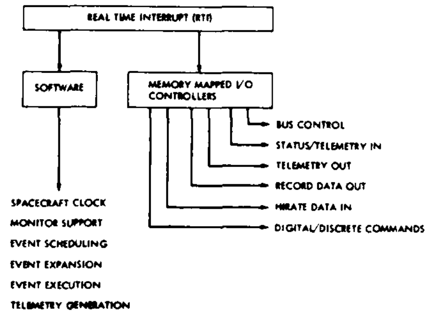
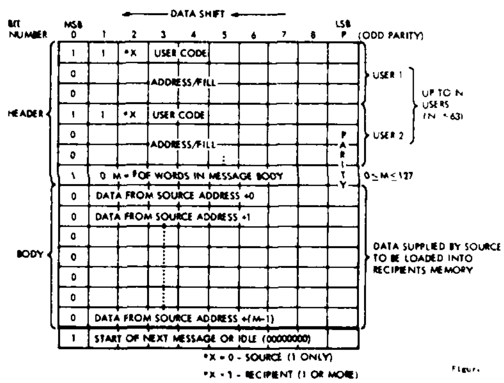


Figure 6

BUS MESSAGE FORMAT CONSTRUCT



Figure

CDS - MEMORY TO MEMORY TRANSFERS

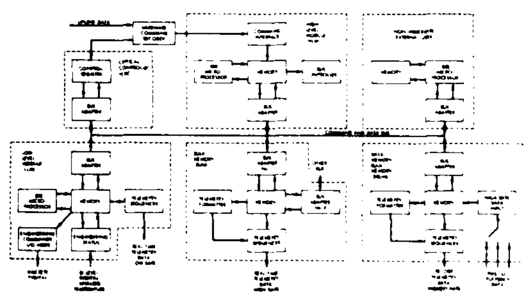


Figure 8

ABSTRACT

BIT SLICE MICROPROCESSOR INFLUENCE ON A SPACEBORNE HIGH THROUGHPUT PROCESSOR ARCHITECTURE

L.F. Bonilla - Hughes Aircraft Co.
K.B. Smernoff - Hughes Aircraft Co.
D.D. Vesely - Hughes Aircraft Co.

The High throughput Processor is an advanced central processing unit designed for real time space processing systems. The primary requirements imposed on the processor were 1) radiation hardening for both total dose and prompt dose protection, 2) minimum power, 3) high reliability for a 10 year mission, 4) high throughput capability. Development risk was to be a minimum.

The architecture selected for use in the processor design was the result of trade-off studies that examined various microprocessor architectures and device technologies. The architecture and device technology that best met the space design requirements uses the Advanced Micro Devices 2900 series low power Schottky (TTL) integrated circuits. The primary element in the processor architecture is the 2901 4-bit microprocessor slice which, along with other 2900 series parts, forms a 16-bit parallel processor.

The processor is a single phase synchronously clocked unit with the machine instruction set implemented through a microprogrammed control unit. The instruction set is a derivative of the Hughes F-18 radar data processor instruction set. This instruction set was selected primarily because it is proven and is compatible with the 2901 microprocessor architecture.

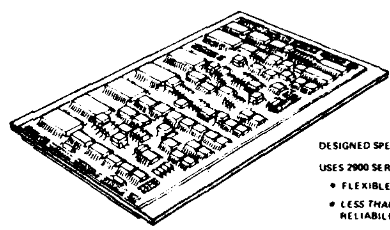
The High Throughput Processor design consists of the arithmetic processing unit, timing and control logic, interrupt logic, power up and power down logic, and system test equipment (STE) interface logic. The power up and power down logic allows the HTP to be power strobed to minimize power as a function of throughput. The STE allows serial access to the processor registers at the system checkout level.

The support software developed for the HTP consists of a cross-assembler, instruction set simulator (non-real-time) and a diagnostics package.

The breadboard design and checkout of the HTP has been completed, and the HTP space quality printed circuit boards are being designed. The HTP will be qualified and then delivered to a spacecraft in the fourth quarter of 1981. A major portion of this work was performed under USAF Contract F04701-77-C-0100 and F04701-79-C-0006.

BIT SLICE MICROPROCESSOR INFLUENCE ON SPACEBORNE, HIGH THROUGHPUT PROCESSOR ARCHITECTURE

HIGH THROUGHPUT PROCESSOR (HTP)



STATE OF THE ART CPU FOR SPACE APPLICATIONS

DESIGNED SPECIFICALLY FOR SPACE USE

USES 2900 SERIES BIT SLICE DEVICES

- FLEXIBLE AND EFFICIENT LSI BUILDING BLOCKS
- LESS THAN HALF THE PARTS AND BETTER RELIABILITY THAN DESIGN WITH MSI/SSI ONLY

SATISFIES HIGH PERFORMANCE APPLICATIONS IN DISTRIBUTED PROCESSOR SYSTEMS

- REAL TIME CONTROL
- DATA AND COMMUNICATIONS PROCESSING
- SPACECRAFT MANAGEMENT

OPTIONAL POWER STROBING TO MINIMIZE POWER AT REDUCED PROCESSING LOADS

HIGH THROUGHPUT PROCESSOR (HTP) KEY FEATURES

DEVICE TECHNOLOGY

- CPU LOGIC: LOW POWER SCHOTTKY TTL (2900 SERIES DEVICES)
- PROM CONTROL MEMORY: SCHOTTKY TTL, NICHROME FUSED LINK

RADIATION TOLERANCE

- $> 10^6$ RAD (Si) TOTAL DOSE
- PROMPT DOSE PROTECTION

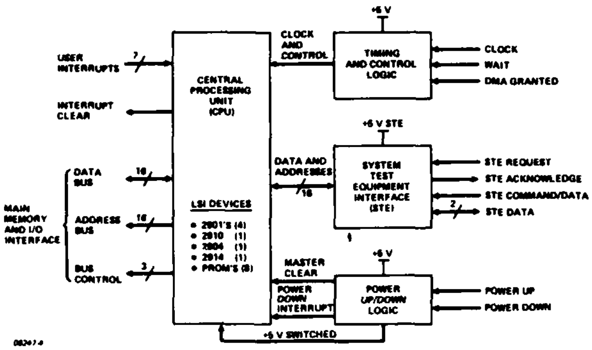
ACCESSORY CIRCUITS INCLUDED WITH CPU

- COMPLETE CLOCK TIMING AND CONTROL LOGIC
- SPECIAL TEST EQUIPMENT INTERFACE TO EASE PROGRAM CHECKOUT AND SYSTEM INTEGRATION

POWER

- WITHOUT POWER STROBING: 18 W
- WITH POWER STROBING: 20 W AT MAX PROCESSING SPEED (POWER UP); 0.5 W STANDBY (POWER DOWN); AVERAGE POWER VS DUTY CYCLE, LINEAR

HIGH THROUGHPUT PROCESSOR (HTP) FUNCTIONAL ARCHITECTURE



HIGH THROUGHPUT PROCESSOR (HTP) FUNCTIONAL CHARACTERISTICS

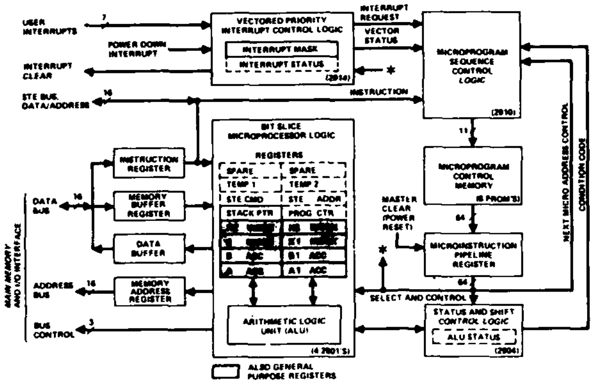
- WORD LENGTH: 16 BITS
- DATA LENGTHS: 32, 16, 8, 4, 1 BITS
- INSTRUCTIONS: 114
- ARITHMETIC: FRACTIONAL, 2'S COMPLEMENT
- USER REGISTERS: 10 (8 GENERAL PURPOSE)
- INTERRUPTS: 8 (1 POWER STROBE)
- I/O: MEMORY MAPPED
- MEMORY ADDRESSING: 15 MODES, UP TO 64K WORDS

HIGH THROUGHPUT PROCESSOR (HTP) FUNCTIONAL SPEED CHARACTERISTICS

FUNCTIONAL PARAMETER	OPERATING SPEEDS WITH CONSERVATIVE DERATING: BENIGN ENVIRONMENT, MINIMAL DERATING	SHORTER TERM MISSIONS, 1 TO 3 YEARS	LONGER TERM MISSIONS, 7 TO 10 YEARS
MICROCYCLE TIME, NS	200	300	400
LOAD, μS	0.6	0.9	1.2
STORE, μS	0.8	1.2	1.6
ADD (MEMORY), μS	0.6	0.9	1.2
ADD (REGISTER), μS	0.4	0.6	0.8
MULTIPLY, μS	4.2	6.3	8.4
DIVIDE, μS	5.2	7.8	10.4
THROUGHPUT, KOPS*	1088	725	544

*ASSUMES AVIONICS INSTRUCTION MIX WITH HEAVY USE OF MULTIPLY (5.2%) AND DIVIDE (1.3%)

HIGH THROUGHPUT PROCESSOR (HTP) CPU ARCHITECTURE



2900 SERIES LSI VS MSI/SSI

LSI FAMILY COMPONENTS USED		ESTIMATED EQUIVALENT MSI/SSI
• 2901A	4-BIT MICROPROCESSOR SLICE (4)	4 X 12 = 48
• 2910	MICROPROGRAM CONTROLLER	20
• 2904	STATUS AND SHIFT CONTROL UNIT	12
• 2914	VECTORED PRIORITY INTERRUPT CONTROLLER	15

7 LSI COMPONENTS EQUIVALENT TO ~ 95 MSI/SSI

LESS PARTS FOR IMPROVED RELIABILITY AND SMALLER SIZE

HTP SUPPORT RESOURCES

SUPPORT EQUIPMENT

- CPU TESTER
- CRT/KEYBOARD MONITOR AND CONTROL

SUPPORT SOFTWARE

- CROSSASSEMBLER
- SIMULATOR
- CPU DIAGNOSTICS (RESIDENT IN HTP)
- HIGHER ORDER LANGUAGE (HOL) COMPILER (PLANNED)

CONCLUSIONS

2900 SERIES BIPOLAR BIT-SLICE FAMILY AND BIPOLAR PROM'S MEET HIGH PERFORMANCE NEEDS

- VERSATILE BUILDING BLOCKS WITH GOOD FLEXIBILITY FOR SPACEBORNE PROCESSORS
- WILL SATISFY MANY SPACECRAFT NEEDS FOR NEXT 5 TO 10 YEARS OR MORE
- GOOD SPEED AND RADIATION TOLERANCE CHARACTERISTICS
- RELATIVELY HIGH POWER; CAN BE REDUCED VIA POWER STROBING

RECOMMENDATIONS FOR BIT SLICE AND MEMORY DEVICES

UPGRADE HIGH PERFORMANCE BIPOLAR LSI COMPONENTS BY ADDING POWER STROBE FEATURES

- ON-CHIP POWER SWITCH PROVISIONS (BIT SLICE FAMILY AND PROM'S)

ENCOURAGE DEVELOPMENT OF LOW POWER, RAD HARD FAMILY OF HIGH SPEED DEVICES

- CMOS OR COMS-SOS BIT SLICE FAMILY – 8 BITS WIDE
- GATE ARRAYS FOR PERIPHERAL LOGIC
- RAM'S: UP TO 4K X 1 OR LARGER
- PROM'S: UP TO 4K X 8 OR LARGER

CMOS/SOS HIGH-PERFORMANCE PROCESSORS FOR FUTURE SPACEBORNE MISSIONS

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RCA, Advanced Technology Laboratories
Camden, New Jersey

ABSTRACT

The successful application of microprocessor-based systems to space applications in the 1980's and 90's presents a challenge to space system designers, computer architectural designers (hardware/software), semiconductor technologists and advanced packaging/manufacturing organizations. Valuable experience from the 1960's and 70's in developing space systems has shown that the approach of building a processor and then applying that processor to a broad set of requirements was one of constant compromise between cost, weight, power, reliability throughput and radiation tolerance. The successful use of microprocessors in space systems requires a thorough knowledge of space applications as well as an awareness of new or anticipated technology developments that may be applicable.

RCA has embarked on a program which combines its space experience with CMOS/SOS technology to develop a family of processors for space applications. The CMOS/SOS technology is generally recognized as a VLSI technology with numerous advantages for military and aerospace applications. RCA is capitalizing on this technology by applying it in rigidly constrained military and commercial systems. It is providing attractive solutions to problems that cannot be matched by the more prevalent commercial technologies. Specifically, we have developed VLSI microprocessors and support circuits for space applications which provide high-speed signal processing, low power and environmental tolerance. This paper describes some of the technology advantages and advanced packaging approaches of CMOS/SOS, and presents a more detailed discussion of results currently being achieved with our high-performance data and signal processors. In particular, characteristics, results and applications of the RCA ATMAC microprocessor and the Air Force sponsored GPU chip set will be presented.

The tremendous potential of CMOS/SOS has been demonstrated in numerous RCA processor designs and embedded processor applications. One of our most successful ventures is the SCP234 spaceborne computer which is currently in service in the TIROS and DMSP satellites. This computer employs a CMOS/SOS memory unit and has provided us with significant reliability data on the technology. The ATMAC microprocessor, developed by RCA Advanced Technology Laboratories, is an excellent example of a signal processing system with a throughput potential of more than 8 million operations per second while dissipating less than 3/4 W of dynamic power. ATMAC's potential is being exploited in numerous computational intensive applications having severe size, weight and power constraints. For example, Hughes Aircraft Co. has selected a multiprocessor ATMAC configuration for the target-tracking functions in the Mini-HALO Experiment, a DARPA sponsored mosaic-sensor, spaceborne surveillance system targeted for launch in the early 1980's.

For lower performance applications, the GPU chip set developed by the Air Force provides an excellent technology implementation which is capable of emulating commercial and military general-purpose computers. This capability is becoming increasingly attractive as DoD and NASA intensify their efforts toward general-purpose computer standardization at the instruction-set architecture level.

INTRODUCTION

The increasing sophistication of aerospace applications demands that computers of the 1980's and 1990's be capable of processing increasingly large volumes of data, much of it in real time. These demands present the system designer with an almost insurmountable challenge, that of designing the optimal processor configuration for his particular application within the constraints of weight, power, reliability and cost. Fortunately, significant advances have been occurring in VLSI circuit technology, packaging and computer aided

design. These provide the designer with tools that greatly simplify his task. VLSI technology is making available reliable high-speed components, while new packaging techniques are providing dense and compact electronic assemblies. Computer aided design techniques applied to both areas are significantly reducing design time and non-recurring development costs.

RCA is using CMOS/SOS technology in both standard and radiation tolerant forms as the basis for developing a family of militarized data and signal processors. These processors are designed for embedded applications where the more prevalent commercial technologies cannot provide the required levels of performance.

This paper briefly describes some of the technology advantages and advanced packaging approaches of CMOS/SOS and a more detailed discussion of results currently being achieved in one of its highest payoff applications — high-performance data and signal processors. In particular, characteristics, results and applications of the RCA ATMAC and the Air Force sponsored GPU chip set will be presented.

CMOS/SOS Technology

Of the present circuit technologies, CMOS/SOS technology provides one of the best speed-power products for system integration (Fig. 1). Its low speed-power product, typically, a tenth of a picojoule, is attributed mainly to the very low on-chip capacitances in typical logic interconnections. Also, since CMOS/SOS is a completely static logic family with no dc paths to ground, dynamic power is a direct function of switching frequency. When applied to microprocessors, the system speed-power product improves even more because only a small percentage of the logic elements (typically 10% to 20%) are changing state during a given instruction execution. Thus, it is possible to have systems with 10,000 gates operating at instruction execution rates greater than 10-MHz which dissipate less than 1 W.

Radiation tolerance, capable of meeting the requirements of strategic weapons systems and long duration space missions, is another key feature of CMOS/SOS. The saphire insulating substrate of CMOS/SOS provides excellent immunity to photocurrents induced during high radiation dose rates. The intrinsic transient dose rate hardness of CMOS/SOS is better than 10^{10} rads per second. Also, the total dose hardness of CMOS/SOS is excellent. Hardness levels better than 10^4 rads are being achieved for standard circuits. For chips designed with specific radiation-hardening circuit-design techniques, these levels are greater than 10^6 rads. These techniques[1] include using a minimum number of transmission gates, restricting logic circuits to not more than three stacked devices, strapping transistor substrates, and selecting proper device ratios.

Several years ago, RCA produced a high-speed code generator using the hardening process and circuit-design techniques just described. The code generator performed at a rate greater than 10 MHz after exposure to over 10^6 rads (Si). The availability of CMOS/SOS circuits that will continue to perform in hostile radiation environments has made it possible to design space systems that operate for long periods. One example of a system that will use RCA's radiation hardened CMOS/SOS technology is the Air Force sponsored Fault Tolerant Spaceborne Computer.

Other characteristics which make CMOS/SOS excellent for space applications include:

- very low power: no static power, dynamic power = CV^2f.
- High device density: 4 to 14 square mils per device for random logic.
- High noise immunity: 45% of supply voltage.
- Fully static logic family.
- Wide operating voltage: 3 to 15 V.
- Wide operating temperature: -55°C to +125°C.

- Very high speed: 1 to 3 ns gate delays.

DoD estimates that the total life cycle costs of electronic equipment over a twenty-year period will be very sensitive to power dissipation and weight, two factors for which CMOS/SOS in an optimum technology. This sensitivity to various applications is indicated below:

Application	Power	Weight
Aircraft	\$20/watt	\$5000/pound
Satellites	\$2000/watt	\$10,000/pound
Battery Powered Field Equipment	\$3000/watt	

Clearly, the low power and excellent VLSI device densities of CMOS/SOS will contribute to significantly lower costs for future aerospace missions.

Computer-Aided Design

One of the most important attributes of CMOS/SOS is its compatibility with fully automatic design automation layout techniques. Many aerospace applications place such rigid constraints on system size, weight and power that VLSI circuits must be used. Consequently, system development costs are increased because they are spread over a relatively small number of components. RCA's low cost approach is to use both gate universal arrays (GUA) and standard cell approaches for circuit design. Coupled with CMOS/SOS technology, they provide quick turnaround solutions for meeting the VLSI requirements of aerospace applications. RCA is currently working on extending the automatic routing programs associated with the standard cell approach to provide an automated universal array (AUA) capability.

One notable application of the standard cell approach and automatic placement and routing design automation was in the design of the two ATMAC microprocessor chips shown in Figs. 2 and 3. The data execution unit chip contains 4560 transistors on a chip measuring 255 x 260 square mils. The instruction and operand fetch unit chip has an area of 259 x 272 square mils and contains approximately 4290 transistors. The storage registers, consisting of fairly regular logic elements, were designed and laid out using normal handcrafted methods; the random logic was implemented with standard cells for automatic placement and routing. The ATMAC program would not have been feasible without design-automation tools, since a total handcrafted ATMAC would have been at least five times more costly and would have delayed the program an additional six to twelve months.

In conjunction with RCA design-automation tools, a full spectrum of simulation and checking programs is used in the design of CMOS/SOS VLSI. Since conventional breadboarding techniques are inadequate a complete package of system, logic and circuit simulation tools is used to more accurately model the LSI circuits under consideration. The end results are components that work correctly the first time through, with reduced design time and lower non-recurring costs.

Advanced Packaging

The extremely low power dissipation of CMOS/SOS VLSI makes it a natural choice for advanced high-density packaging techniques which can optimize the size and weight of electronic systems. As previously indicated the cost of flying electronic equipment is very sensitive to weight. Thus, advanced packaging approaches can be quite important in minimizing total life cycle costs of aerospace systems.

Conventional packaging of VLSI chips mounted in ceramic dual-in-line packages on printed-circuit boards produces low system packaging densities. The problem arises because VLSI chips often require more pins per chip than MSI and SSI. The standard 64-pin dual-in-line package used in many of our VLSI applications occupies an area of 0.9 inch by 3.4 inches to mount a chip that is less than ¼ inch on each side. This area requirement is extremely inefficient and results in systems that are much larger and heavier than necessary.

An advanced packaging approach successfully used by RCA is a thick-film ceramic

interconnect board approach with chips mounted in leadless hermetic chip carriers.[2] The chip carriers generally have pins mounted on all package edges, utilizing pin spacings of 30 to 50 mils. These packages are reflow soldered to a ceramic multilayer thick-film interconnection substrate. Figure 4 shows the size reduction obtained when the 10 ICs comprising a 16-bit ATMAC microprocessor and its associated special function unit were repackaged. Figure 5 shows a close up of the subassembly. Use of the substrate and chip carrier approach can yield up to a 10-to-1 size reduction over conventional printed circuit board and dual-in-line package techniques.

Dense memory systems are an important segment of any processor-base aerospace electronic system. Under AF contract, RCA has applied CMOS/SOS 1K RAM chips, leadless hermetic chips carriers, and the thick-film ceramic interconnect approach to the Navy's ISEM packaging format to produce a very dense memory system. Figure 6 shows one side of a doublesided substrate which contains 64 RAM chips and 40 resistors producing a memory module containing 8K words x 16 bits in a volume of about 2.25 cu in. Using this format and RCA's latest 4K CMOS/SOS RAMs the module would have a total storage capability of 32K words.

ATMAC MICROPROCESSOR

ATMAC Architecture

Approximately five years ago, RCA Advanced Technology Laboratories started development of a very high speed programmable signal processor for real-time applications in rigidly constrained systems. This processor, called ATMAC, has great payoff potential in high-throughput oriented applications where existing microprocessors cannot meet the system requirements.

The ATMAC architecture shown in Fig. 7 is capable of executing a full computational repertoire of 189 instructions, with throughput of about 3 million operations per second. The total amount of hardware necessary for a system is minimized because ATMAC uses bidirectional buses for interconnections with peripheral equipments and subassemblies. The bidirectional bus system (Fig. 8) reduces the number of connections and allows asynchronous communication with program memory, data memory, I/O devices, and special function units (such as a hardware multiplier or accumulator). ATMAC system throughput is optimized by a high degree of functional parallelism. Throughput is at least three times greater than that of general-purpose architectures with equivalent cycle times.

Most of the current ATMAC applications are based on a 16-bit processor configuration with a hardware 16-bit x 16-bit multiplier/32-bit accumulator special function unit. The complete processor assembly shown in Fig. 5 consists of 10 CMOS/SOS VLSI chips dissipating less than 1.2 watts of dynamic power and is a very powerful signal processing module. The system can perform basic multiply/accumulate oriented operations (the basic operation required in many digital signal processing algorithms) in less than 700 ns. per pair of data memory operands. In addition, the module performs very efficient fast-fourier transforms (FFTs), which allow information to be extracted from signals in the time domain by transforming them into the frequency domain. The modular sections of an FFT program have been written for the ATMAC microprocessor so that the execution time, I/O time, scaling time, and memory-size requirements for both the program and data memory can be estimated. For many applications, the execution times are short enough to allow real-time FFT processing (see Table I). Results show that ATMAC memory requirements for a moderate number of data points are very reasonable.

The power dissipation for a full 16-bit machine configuration is less than 3/4 W at full speed and 10 V operation, while its static power requirement is approximately 10 mW.

ATMAC Applications

ATMAC is currently being used in several military programs having high performance and low power requirements. New applications

are being reviewed continually. Applications considered include guidance computers for spacecraft, missiles, torpedoes, and RPVs; electronic warfare systems; radar applications, navigational systems; and communication systems. Descriptions of two current RCA programs follow.

Application to Speech Processing

A narrowband speech processing system was ATMAC's initial target application. Here ATMAC was used to apply linear predictive coding (LPC) theory to speech bandwidth compression for digital transmission of voice over telephone lines. For the current LPC algorithm implemented on ATMAC, the speech spectrum is described as the coefficients of a 10th order all-pole filter. The spectrum of the impulse response of this filter closely approximates the envelope of the original speech spectrum. Pole values are calculated by evaluating an autocorrelation function and performing a simple recursion.

The ATMAC implementation of the LPC system is shown in Fig. 9. The special function unit is a 16 x 16 bit two's complement multiplier with a 32-bit accumulator. The ATMAC DMA facility is used for transferring speech data to and from the system. Both input and output are accomplished with a single DMA facility by interleaving input and output data in memory. Execution times and memory requirements for the LPC algorithms (assuming a 70-ns clock cycle) are given in Table II.

A complete speech terminal capable of both modem and linear predictive processing can be implemented with less than 50 LSI arrays. The entire system could be housed in a 5 x 5 x 10 inch package with power dissipation of less than 5 W.

Application to Sonar Signal Processing

In mid 1978, RCA assembled, programmed, tested and demonstrated an ATMAC-based system that performs adaptive spatial beam forming, complex translation, and digital filtering for processing sonar signals in realtime. ATL recently completed fabrication of the full scale development hardware for deployment (Fig. 10). This system uses a dual ATMAC processor configuration to perform realtime computations. The two 16-bit ATMAC CPU's interface to an array channel for realtime data collection, a secure communications channel for transferring processed data to a shore station, and a console channel for system initialization and debug. The CPU's perform spatial and frequency filtering, and transmit the results of this processing to a shore station via a UHF satellite link. The realtime processing is directed via commands received from the shore station and processed by the computer system while realtime processing is proceeding.

The processing functions, execution times and memory requirements of CPU-1 and CPU-2 are listed in Tables III and IV. This dual-processor ATMAC system in Fig. 10 is implemented on seventeen 6 x 7 inch circuit boards, occupying less than 0.65 ft.^{3} and dissipating less than 10 W total power.

RADIATION-HARDENED MICROPROCESSOR CHIP SET

Description of the Family

In 1975, the Air Force Avionics Laboratories embarked upon a major development program with RCA to develop a radiation-hardened microprocessor chip set intended for emulating general-purpose computers.[3] This is a flexible bit-slice family of building blocks which provides a cost-effective development approach for radiation hardened versions of key microprocessor families. In addition, the family provides the Air Force with a technology to replace obsolete microprocessors from single-source suppliers as the devices become unsupported.

RCA is exploring numerous architectures aimed at efficient emulations (high performance with reasonable hardware structures) of the various tri-service instruction set architecture standardization programs. In all of these programs, the GPU chip set offers a low-cost development approach for high-technology improvements in existing general-purpose computers (microprocessors, minicomputers

or even main-frame processors), hardware compatible with embedded (small size, weight, and power dissipation) processor utilization, and substantially improved performance and environmentally tolerant components. A key benefit of this approach is that substantial improvements, in basic computing devices can be realized while maintaining compatibility at the user instruction set level. This represents a large savings of existing support software tools which industry and DoD estimate to be worth over $30 million dollars per computer type.

A standard military computer configured in the GPU chip set would have an immediate high volume market. An ideal application example is the GPS user equipment. The embedded processor requirements of this application base are tailored toward a militarized, small size, low-power, radiation tolerant, high performance, general-purpose computer with high level language programmability. A GPU-based machine standard military computer would be an ideal solution.

RCA is currently under contract to the Air Force Materials Laboratory (AFML) to develop the CMOS/SOS manufacturing technology for the Radiation Hardened Microprocessor chip set. Current members of the family include:

1) General Processor Unit (GPU). An 8-bit slice LSI component with a 16 word register file, latches, shifters, an arithmetic logic circuit which can perform add's, and's, or's and compliment's. Parts have been built, and can perform register to register operations in less than 250 ns.

2) Memory. A 1K RAM is available with a 100 ns access time. 4K parts may also be available for this effort.

3) Microsequencers. Two microsequencers have been designed and are now being fabricated by RCA. One is a functional duplicate of the 2910. The other is a device which grew from the GPU design and the desire to emulate many instruction sets with one GPU chip set. It has many features of the 2910 and the 2904.

4) 8 x 8 Multiplier. This multiplier has an 8 x 8 multiply time of 200 ns, and is concatenable. Four stages of Booth's algorithm are used to produce a 16-bit result.

5) Gate Universal Arrays (GUA's). Mask programmable logic arrays have been designed to provide custom interconnection between the LSI integrated circuits of the GPU chip set. Four sizes are available: 182, 300, 452 and 632 gates with 40, 48, 64 and 64 I/O pads respectively.

6) ROM. A 1024-bit mask programmable is available with an access time of 120 ns. This ROM is designed for fast control store applications and has CMOS compatible outputs.

Higher density RAMs and ROMs compatible with 10-MHz micro-cycle operation are available within RCA and will eventually become part of the AF chip set. A 4k static CMOS/SOS RAM, the TCS 210, was used in the PDP-11 emulation system described later and is being used in several RCA military applications. The part uses 5-micron buried contact design rules and achieves 10-volt operation with an access time of less than 100 ns. The basic layout and memory technology are being applied to development of a 16K static CMOS/SOS RAM and an 8K mask program ROM. Both have access times of less than 100 ns and are compatible with emulation architectures. Finally, a higher performance GPU chip set using narrow channel lithography (4-micron channel lengths) is currently in planning states and, if developed, the components could provide performance capabilities in excess of bipolar at a fraction of the power dissipation.

Application to a PDP-11 Emulation

RCA designed, fabricated, debugged, and demonstrated a PDP-11 emulation

demonstration system using the GPU chip set as basic building blocks (Fig. 11). The goals of the program were specifically aimed at showing the feasibility of emulating commercial or standard military computers with the GPU chip. Also, the compatibility of existing support software (i.e., debug packages, assemblers, editors, etc.) of the target machine would be demonstrated on the new machine architecture. The ultimate result of the program would show the technology advantages of CMOS/SOS (substantially improved size, weight, power, and performance) in a military computer application base while being compatible with a wealth of existing support software. The complete design, fabrication and debug of the demonstration system was funded on a very modest budget, demonstrating the low development cost of this approach.

The PDP-11/40 standard instruction set was chosen as the target machine for the emulator demonstration because of its widespread use within the military. However, the specific selected target machine was not the primary focus of the demonstration since the design techniques, and development cycles, are common to any selected target machine within the minicomputer class. Demonstration of the feasibility and resulting improvements of this emulation approach for military computers was the key goal.

Figure 12 shows a general block diagram of the PDP-11 emulation architecture. The system is oriented around a two-bus organization including a 16-bit unidirection address bus and 16-bit bidirectional data bus. The system uses PDP-11 compatible memory mapped I/O, but bus control and electrical interfaces were designed specifically for this architecture and are not UNIBUS compatible.

Three key CMOS/SOS building blocks were used in the demonstration, including: the GPU, CMOS/SOS 2910 microprogram sequencer, and RCA TCS 210 4k static RAM. In the demonstration system, the logic requirements for these auxiliary functions were satisfied with off-the-shelf TTL and CMOS MSI and SSI components, but they could later be replaced with GUAs or standard cell custom LSI in actual productizing of architecture. The architecture incorporated parallelisms and pipelining wherever reasonably possible to achieve a high throughput capability.

To project the capabilities and potential of an all-LSI version of the emulation architecture paper designs at the detailed register/bus level have been performed. Two new chip types would be needed. Each would be relatively simple to develop and amenable to either GUA or standard cell custom LSI implementation. The first type would be a four-bit slice through the data path support functions with four chips required for the 16-bit system, while the other chip type would integrate all the control support functions augmenting the 2910. With these two new types and a 512 word x 8 bit CMOS ROM, an all-LSI system would require a total of only 18 LSI components, as shown below:

2910 microprogram sequencer	- 1
GPU chips	- 2
GPU support chips (new type #1)	- 4
Sequencer support chip (new type #2)	- 1
Microprogram and mapping ROM chips	-10
TOTAL	18

In addition to small size, the all-LSI emulator would have a dynamic power dissipation at full operating frequency of approximately 2-3 watts and a static dissipation of less than 50 milliwatts.

Detailed performance comparisons of the CMOS/SOS emulator approach and the various DEC PDP-11 models were made. Table 1 shows a weighted average performance comparison of the RCA CMOS/SOS Emulator and the projected all-LSI emulator against the various PDP-11 models. The instruction mix used in the comparisons was taken from C.G. Bell et al, "Computer Engineering". As shown in the table, the breadboard system was slightly better than the PDP-11/40 while the all-LSI emulator would be very close to the DEC's top of the line, the PDP-11/45, with a throughput potential of approximately 790 KOPs.

CONCLUSIONS

CMOS/SOS technology has proven its capability and viability for real-time data and signal

processing applications. The material presented in this paper has shown how the CMOS/SOS technology can be applied to real-time signal processing applications, all with low power requirements. The flexibility of the technology allows system designers to configure processor architectures as simple as arithmetic processors, and as complex as distributed processor networks. Further, the technology provides designers with the capability to produce equipment that will withstand the high radiation environment encountered in satellites and missiles. In summary,

1. The CMOS/SOS technology, fully automated custom LSI design capability, coupled with advanced packaging techniques provides an ideal technology base for future space missions.

2. The RCA ATMAC microprocessor is an example of an ideal signal processor primitive for computationally intensive aerospace applications.

3. The AF sponsored GPU chip set provides an excellent building block family for emulating commercial and standard DoD data processing instruction set architectures. The resulting implementations provide substantially improved performance, size, weight and power dissipation over existing implementations as well as intrinsic environmental tolerances that are being demanded in future space missions.

RECOMMENDATIONS

1. DoD/NASA should develop through industry a detailed CMOS/SOS technology data base required by space processor designers.

Elements of the data base should include:

- CMOS/SOS reliability
- CMOS/SOS radiation hardening
- CMOS/SOS basic building blocks circuits and chips such as RAMs and ROMs
- Fault-tolerant concepts that are implementable in CMOS/SOS technology
- Space packaging concepts
- Software development tools that can be used to simulate space processors requirements
- Space experiments that allow gathering information that supports space processor designs

2. DoD/NASA space applications require technology performance levels that exceed commercial requirements. Therefore, DoD/NASA must fully develop sources for the highly reliable radiation hardened technologies like CMOS/SOS that will be required to satisfy the space processor requirements of the 1980's and 90's.

3. DoD/NASA should initiate the development of a CMOS/SOS microprocessor version of MIL-STD-1750. The speed, density and CAD tools of CMOS/SOS have matured to the point that a VLSI version of MIL-STD-1750 can be implemented with low risk and within a reasonable development cycle. Such a device would substantially improve today's avionics processors and would have broad applicability in embedded avionics systems. In addition, a viable product of this nature would enhance the feasibility of the Air Force's computer standardization programs and provide tremendous life-cycle cost benefits for future avionics missions.

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TABLE I. FFT EXECUTION TIMES FOR AN ATMAC MICROPROCESSOR SFU MULTIPLIER

No. of Complex Points	Data Memory Words	Execution Time (ms)
64	320	0.869
128	640	1.897
256	1230	4.295
512	2560	9.660
1024	5120	19.485

Program memory requirements - 620 words

TABLE II. PROGRAM MODULES & ALLOTMENTS FOR SPEECH PROCESSING SYSTEM

	Execution Time (ms)		Memory	
Algorithm	As Presently Coded	With Improve-ments	Program (24-bit words)	Data (16-bit words)
LPC Analyzer	7.46	6.30	1373	1073
LPC Synthesizer	2.85	2.85	1441	1021
Modem Transmitter	6.18	2.53	458	610
Modem Receiver	5.43	2.84	864	1212

TABLE III. PROGRAM MODULES & ALLOTMENTS FOR ATMAC CPU 1

	Maximum Execution Time (μs)	Memory Requirements	
Algorithm		Program (24-bit words)	Data (16-bit) words)
Array Interface Control and Data Shading	130	25	21K* 27
Beamforming	420	20	540
Cosine and Sine Value Computation	300	60	180
Low Power Idle	3	10	—
Receiver Interface	10	50	225
Interprocessor Communication	10	25	3
Totals	873	190	21K* 975
*8-bit words			

TABLE IV. PROGRAM MODULES & ALLOTMENTS FOR ATMAC CPU 2

	Maximum Execution Time (μs)	Memory Requirements	
Algorithm		Program (24-bit words)	Data (16-bit words)
DMA Channel Servicing	4	5	—
Beam-Band Pair Connection	45	10	120
Complex Translation	100	35	60
Scheduling - Filters, Sat Comm, Other I/O	40	100	20
Low-Pass Filtering	500	220	6120
Output Formatting & Data Buffering	50	75	1700
Transmitter Interface	20	15	—
Low Power Idle	5	15	—
Interprocessor Communication	10	50	10
Totals	774	525	8030

TABLE V. PERFORMANCE RESULTS & ALL-LSI PREDICTIONS VERSUS EXISTING PDO-11 MODELS

Weighted Average							
	Micro Cycle Time	Fetch	Source Fetch	Destination Fetch	Execution	Total	Relative To LSI-II
LSI-11	400ns	2.514	0.689	1.360	1.320	5.883	1.000
PDP-11/10	300ns	1.500	0.573	0.929	1.094	4.096	1.436
PDP-11/20	280ns	1.490	0.468	0.802	0.768	3.529	1.667
PDP-11/40	140-300ns	0.958	0.260	0.294	0.575	2.087	2.819
ATL CMOS/SOS Emulator	400ns	0.000	0.228	0.372	1.423	2.023	2.908
PDP11/60	170ns	0.541	0.185	0.218	0.635	1.578	3.727
LSI Emulator	250ns	0.000	0.142	0.233	0.889	1.264	4.653
PDP-11/45 (With Bipolar Memory)	150ns	0.363	0.101	0.213	0.185	0.863	6.820

Data from C.G. Bell et al. "Computer Engineering" P. 327-355

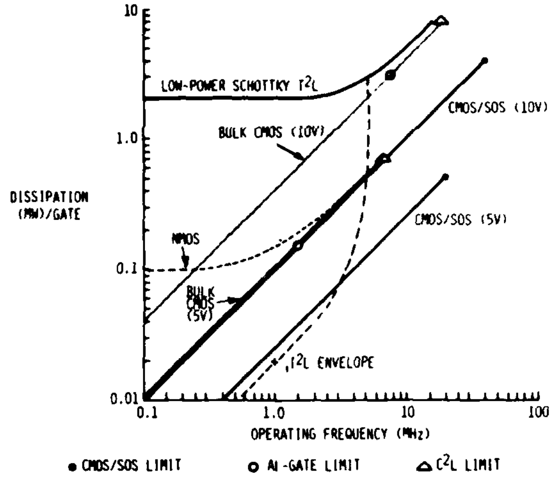


Fig. 1. Technology Speed-Power Tradeoffs. Complementary technologies, such as CMOS/SOS, have essentially no quiescent power dissipation, so power is directly proportional to operating frequency.

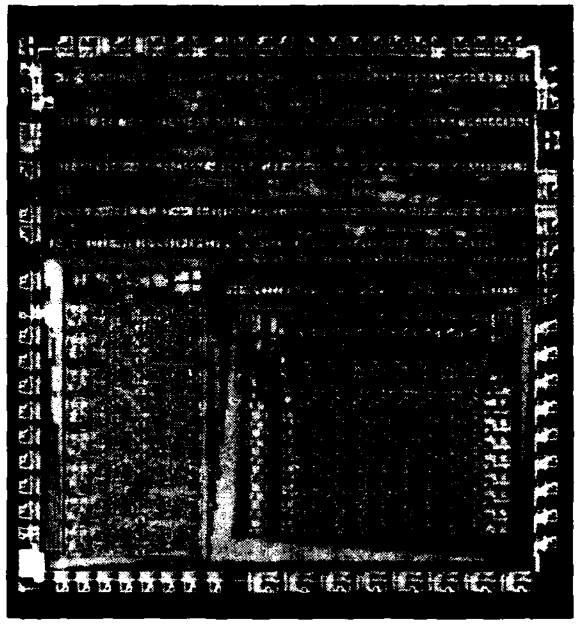


Fig. 3. Instruction and Operand Fetch Unit.

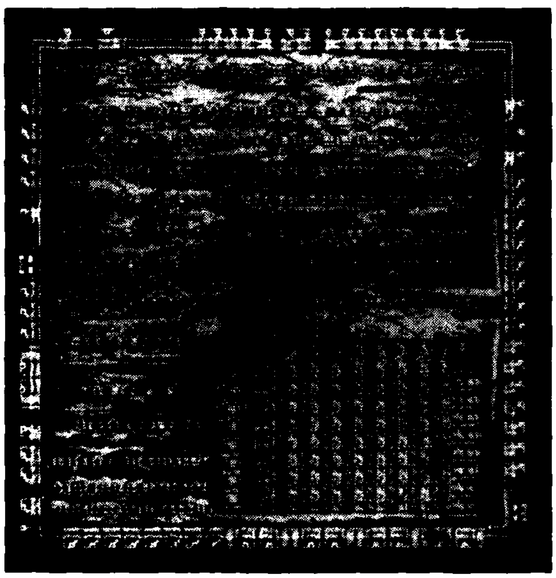


Fig. 2. Data Execution Unit.

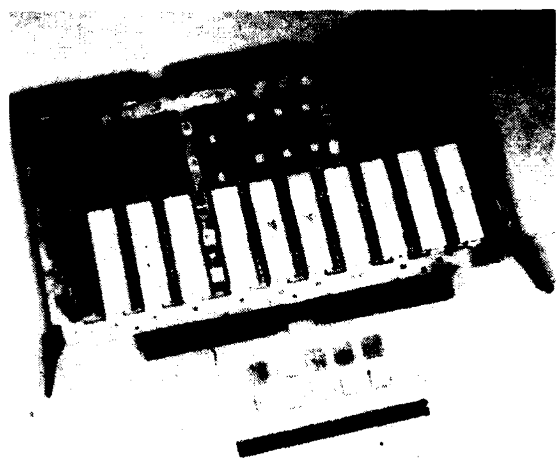


Fig. 4. Comparison of Packaging Techniques. The area occupied by the 10 64-pin ICs is reduced 5 to 1 by using leadless hermetic chip carriers.

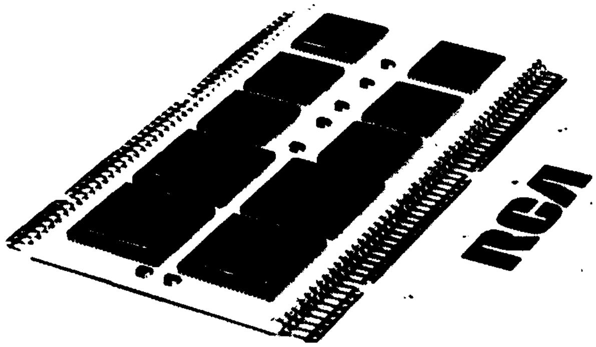


Fig. 5. ATMAC Microprocessor and SFU Multiplier Assembly. The four large packages contain the 16-bit microprocessor. This assembly measures 2.5 x 5.0 inches.

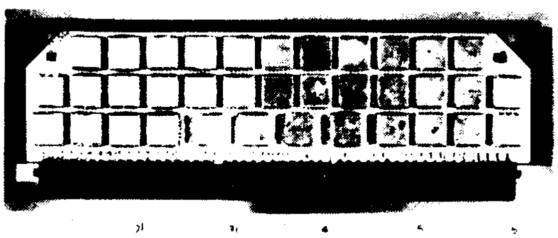


Fig. 6. 70-Chip Double-sided Hybrid in Improved Standard Electronic Module (ISEM) Format.

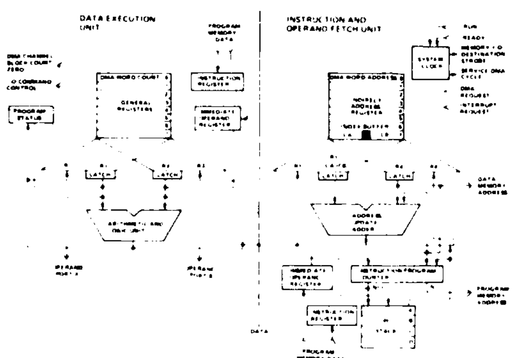


Fig. 7. ATMAC Microprocessor Block Diagram. A two-chip configuration is used to allow parallel operations.

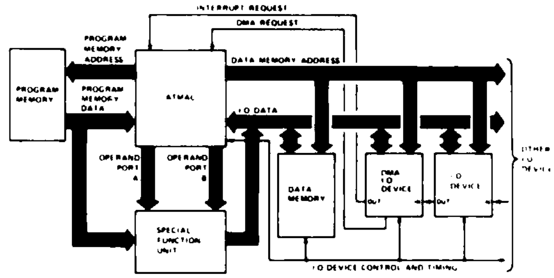


Fig. 8. ATMAC System Block Diagram. The bidirectional bus allows asynchronous communication between the microprocessor and memory, I/O or spec special function units.

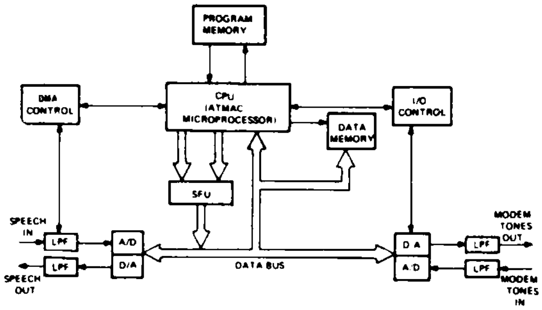


Fig. 9. Laboratory Model Speech-Bandwidth Compression System. High-quality speech resulting from linear predictive coding techniques can be demonstrated with this system.

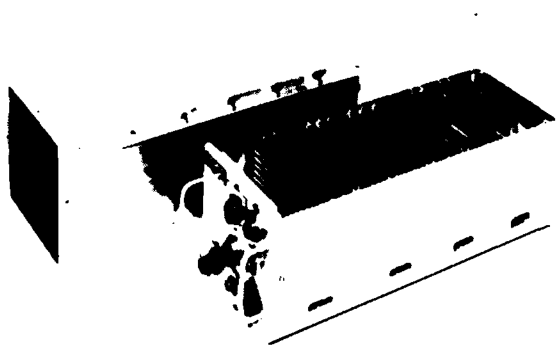


Fig. 10. Sonar Signal Processor Full-Scale Development Equipment.

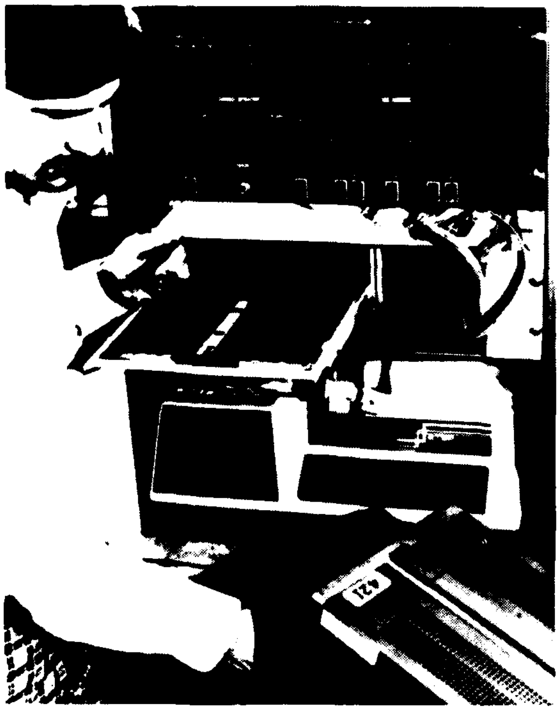


Fig. 11. PDP-11 Emulation System. This demonstration unit uses the CMOS/CMOS/SOS GPU and Microprocessor developed by the Air Force as well as RCA's 4K CMOS/SOS static RAM.

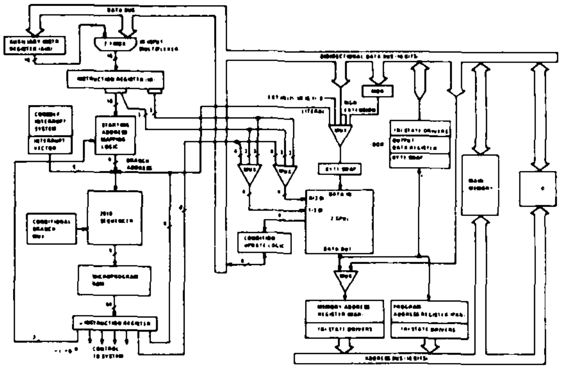


Fig. 12. Block Diagram of GPU-based PDP-11 Emulator.

DoD PROBLEMS AND DEVELOPMENT THRUSTS IN SIGNAL PROCESSORS

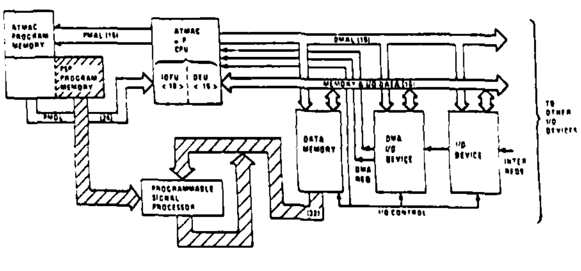
- DoD's FUTURE WEAPON SYSTEMS REQUIRE DRAMATIC IMPROVEMENTS IN PROCESSING THROUGHPUT.
  - MOST FUTURE SYSTEMS ARE SIGNAL-PROCESSING-ORIENTED.
- SIGNAL PROCESSORS HAVE BEEN TRADITIONALLY IMPLEMENTED USING CUSTOM DEDICATED APPROACHES.
  - HORRENDOUS DEVELOPMENT COSTS AND SCHEDULES.
  - INFLEXIBLE AND SPECIALIZED TO SPECIFIC APPLICATIONS.
  - DIFFICULT TO INSERT NEW TECHNOLOGY.
- COMMERCIAL SEMICONDUCTOR INDUSTRY HAS NOT ADEQUATELY ADDRESSED THIS TECHNOLOGY
- DoD AND DARPA ARE FUNDING SEVERAL PROGRAMMABLE SIGNAL PROCESSING PROGRAMS.
- DoD ESTABLISHED $210 MILLION TRI-SERVICE VHSIC PROGRAM TO SPECIFICALLY IMPROVE DoD SIGNAL PROCESSING CAPABILITIES.

DoD FUTURE SYSTEMS WILL REQUIRE ADVANCED PROCESSING PRIMITIVES

- > 90% OF DoD FUTURE SYSTEMS WILL BE CONFIGURED WITH EMBEDDED PROCESSORS.
- DoD SYSTEMS ARE DEMANDING 10-100X THROUGHPUT IMPROVEMENTS.

SYSTEM	PLATFORM	THROUGHPUT - MOPs PRESENT	FUTURE
RADAR	AIRCRAFT/SPACECRAFT	1 - 10	100 - 500
ASW	BUOYS	5 - 15	50 - 500
VIDEO/IMAGING	MISSILES/RPVs	10 - 20	200 - 1,000
ELECTRONIC WARFARE	AIRCRAFT/LAND-BASED	15 - 50	1,000 -10,000

Tightly-Coupled ATMAC System Architecture



CMOS/SOS is the Ideal Technology for Standard Military Computers

- COMPLETE CPUs WITH ECL SPEEDS ARE REALIZABLE ON A FEW NUMBER OF CHIPS
- VERY LOW POWER CV^2f
- VLSI DENSITIES: 2,000 GATES TODAY, ~20,000 GATES WITHIN 5 YEARS
- VERY HIGH SPEED: 3-5ns TODAY; ~1ns WITHIN 5 YEARS
- INTRINSIC AND ENHANCED RADIATION HARDNESS

  TRANSIENT RATE – ~5 X 10^{10} RADS/SEC.

  TOTAL DOSE – 10^6 RADS
- ALL THE NORMAL ADVANTAGES OF CMOS
- COMPATIBLE WITH DA LAYOUT TECHNIQUES

CAD/DA System Required for Successful System and Support VLSI Development

RCA IS AN INDUSTRY LEADER IN DA FOR VLSI

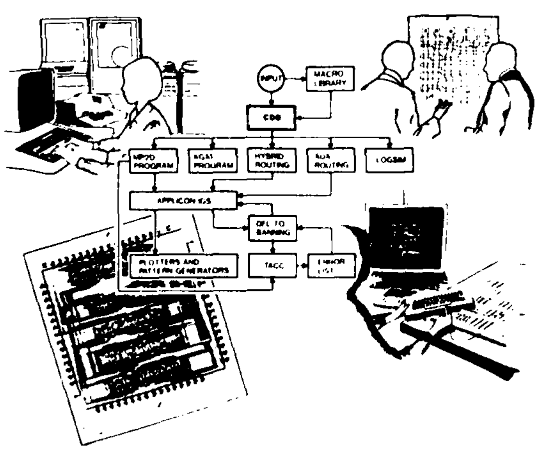
- PIONEERED STANDARD CELLS & MP2D
- ACCURACY & QUICK TURNAROUND IS ESSENTIAL FOR DoD VLSI
- SEVERAL CMOS/SOS STANDARD CELL FAMILIES EXIST – 7 MIL (HIGH SPEED) 4.2 MIL (HIGH DENSITY), 6.3 MIL (RAD-HARD), NARROW CHANNEL (IN DEVELOPMENT)

RCA ACTIVELY USES HIERARCHIAL LAYOUT APPROACHES

- CUSTOM
- STANDARD CELL
- AUTOMATIC UNIVERSAL ARRAY

RCA'S INTEGRATED CAD/DA SYSTEM IS ESSENTIAL

CADDAS Data Management



Simulation and CAD Essential for VLSI ADP Implementation

CONVENTIONAL BREADBOARDING NOT APPLICABLE

- TOO EXPENSIVE
- NO FEASIBLE 1-TO-1 IMPLEMENTATION
- LONG DEVELOPMENT CYCLE

SIMULATION AT ALL STATES OF ADP DEVELOPMENT

- SYSTEM SIMULATION (BUS, REGISTER LEVEL) – ALSIM, APL, N.mPc, ISPL
- LOGIC LEVEL SIMULATION – LOGSIM, MIMIC, ETC.
- CIRCUIT LEVEL – RCAP, SPICE

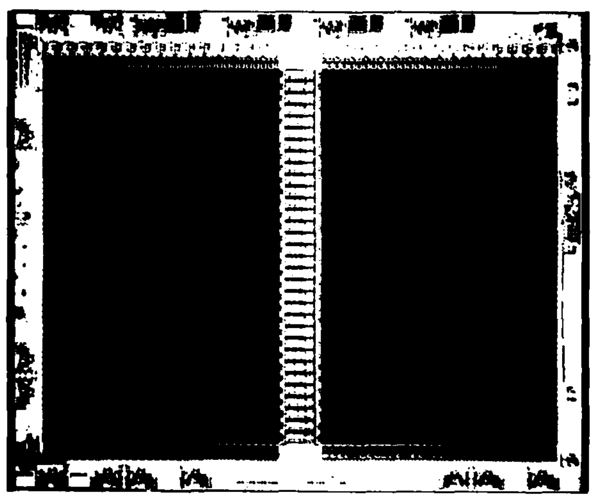
DESIGN AUTOMATION AND OTHER CAD

- CIRCUIT CHECKING – CRITIC
- CHIP CHECKING – TACC
- MULTI-PORT TWO-DIMENSIONAL PLACEMENT AND ROUTING
- MACRO LOGIC AUTOMATIC LAYOUT
- FAULT SIMULATION AND TEST SEQUENCE GENERATORS

RCA Has A Variety of CMOS/SOS Memories to Support Standard Military Computers

MEMORY	ORGANIZATION	SPEED	DYNAMIC POWER	STATUS
RAMs				
TCS-210	1Kx4	100 ns.	20 mw/MHz	AVAILABLE
TCS-165	4Kx1	50 ns.	15 mw/MHz	AVAILABLE
TCS-130	4Kx4	100 ns.	56 mw/MHz	IN EVALUATION
ROMs				
TCS-190	8Kx8	100 ns.	20 mw/MHz	IN DESIGN
TA10682	1Kx8	250 ns.	12 mw/MHz	IN DESIGN

16K CMOS/SOS RAM



CMOS/SOS Reliability

1024 by 1-Bit RAM

Lot	Life-Test Voltage	Sample Size	Functional Failures 1000 Hrs	Total Hours Tested	Functional Failures
1	10	12	0	3624	0
2	10	19	0	3288	0
3	10	18	0	3624	0
4	10	14	0	5802	1(5466 hr)
5	10	45	0	1000	0
6	5	21	0	3316	0
7	5	16	0	3316	0
8	5	8	0	3316	0
9	5	13	0	5730	0
10	5	77	0	1000	0
11	10	77	0	1000	0
12	5	77	0	1000	0

- TOTAL NUMBER OF SAMPLES = 397
- TOTAL HOURS OF TESTING = 752,130
- SCREENED DEVICES @ 125ºC
- FAILURE RATE = 60% CONFIDENCE
  - T = 125ºC, 0.54%/1000 HRS.
  - T = 55ºC 0.0006%/1000 HRS (ACTIVATION ENERGY OF 1.1 eV)

TIROS-N Use Data for CMOS/SOS

CDP 1821 RAM

DEVICES	HOURS	DEVICES HOURS*	FAILURES
306	11,064	3.38×10^6	0

*AS OF 18 JAN. 1980

- T = 10°C
- V_{DD} = 5V
- MTBF = 3.65×10^6 HRS., 60% CONFIDENCE
- DEVICES HOURS DATA TO 18 JAN. 1980

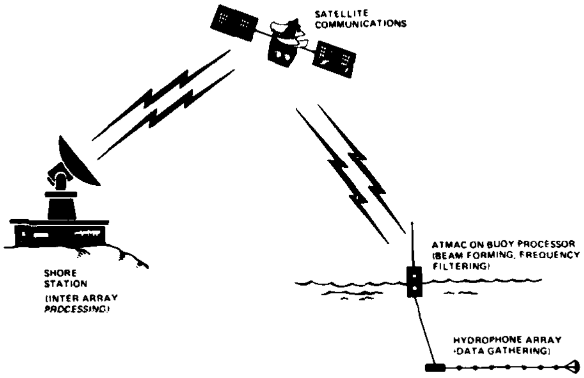
A WORD LENGTH EXPANDABLE TWO CHIP TYPE, 8-BIT WIDE SLICE, MICROPROCESSOR. HIGH PROCESSING SPEED ACHIEVED THROUGH OVERLAPPED OPERATIONS, THE USE OF SPECIAL FUNCTION UNITS AND I-O TRANSFERS USING A DIRECT MEMORY ACCESS CHANNEL.

CMOS/SOS CONSTRUCTION USED.

Microprocessor Features

- 189 INSTRUCTIONS
- ALL INSTRUCTIONS EXECUTED IN ONE MACHINE CYCLE
- APPROXIMATELY 3 MILLION INSTRUCTION PER SECOND
- DATA & PROGRAMS IN SEPARATE MEMORIES
- DATA PATH EXPANDABLE IN 8 BIT MODULES
- DATA & PROGRAM MEMORY ADDRESSING INDEPENDENTLY EXPANDABLE IN 8 BIT MODULES
- ARCHITECTURAL FEATURES PERMITTING MULTIPLE PARALLEL OPERATIONS
- DMA CHANNEL
- SYNCHRONOUS & ASYNCHRONOUS I-O OPERATIONS
- PROGRAM INTERRUPT
- SYSTEM CONNECTIONS PROVIDED FOR SPECIAL FUNCTION UNIT (SFU)
- CMOS/SOS IMPLEMENTATION
- LOW POWER CONSUMPTION - 16 BIT CPU 3/4W

Advanced Autonomous Array [A^3] Concept



CMOS/SOS Emulation of PDP-11

- STANDARD INSTRUCTION SET OF PDP-11/40
- PARALLELISM AND AUXILIARY HARDWARE PROVIDED FOR HIGH THROUGHPUT EMULATION
- COMPATIBLE WITH AN ALL CMOS/SOS LSI APPROACH
- FIRMWARE OR HARDWARE FLOATING POINT CAN EASILY BE ADDED
- BASED ON GPU & CMOS/SOS 2910

RCA's PDP-11 Emulation System is Fully Operational with Three Key CMOS/SOS VLSI CHIPS

- GPU RALU
- CMOS/SOS 2910 MICROPROGRAM SEQUENCER
- TCS-151 4K RAM

} PART OF AF RAD-HARD MICRO-PROCESSOR FAMILY

THE IMPACT OF LARGE SCALE INTEGRATION ON SPACECRAFT ARCHITECTURE

Phillip E. Holt

PROJECT ENGINEER,

THE AEROSPACE CORPORATION

In order to discuss the subject in this very brief overview, some early definitions are helpful:

Architecture: A collection of data processing elements which are configured to perform a specific task or set of tasks.

Autonomy: The ability of a spacecraft to operate in a sustained manner with no external command or control influences; perhaps with inputs from its own sensors.

Throughput: Simply a measure of the rate at which jobs are completed by a processing system.

Spacecraft architecture has been impacted by LSI technology in two major ways: Indirectly, largely as a result of the explosive growth in ground-based, commercial computing cababilities; and directly, due mostly to economies in cost, power, weight, size and in reliability considerations.

The indirect impact results from today's ability to plan and execute complex, long-term space missions. Such planning has demanded the design of high-reliability processing capabilities. In order to achieve these high reliabilities, direct implementation of traditional designs has been accomplished using LSI components.

What has LSI really bought us in terms of spacecraft computer architecture? The answer seems to be, in large part, that reliability considerations have been the major driver. These considerations have resulted in architectures which treated the following items:

- o Modular Designs
- o Redundancy
- o Fault Isolation
- o Majority Voting
- o Multiple Fault Tolerance

However, in general, with the above exceptions, we have generally succeeded only in implementing architectures of the 1960's with 1970's LSI components.

The results of several recent surveys of today's space-qualified computers produces a composite picture of the "average" space computer:

o Speed	300 KIPS
o Memory	64 K Words
o Power	50 Watts
o Weight	30 Pounds
o Size	600 Cubic inches

Obviously, any individual space computer will not have identically the above characteristics, but one can be assured it will not differ from these characteristics by an order of magnitude.

Furthermore, if one wants to buy a space computer, one quickly discovers that the selection is limited. For a specific application one would be fortunate to find more than a handful of candidates. In total, there are probably fewer than 30 models of space-qualified computers available today.

Space computers fall into either of two broad categories:

- o General Purpose - these are software programmable and used typically in applications such as Attitude Control and so-called Housekeeping.
- o Special Purpose - these are often hard wire programmed to function essentially as programmed sequencers.

Substantially all space computer designs are five to ten years old: the equivalent of two or three computer generations.

What areas have been impacted by LSI? Certainly, the most obvious relief has come in power, weight and size. Cost has reduced substantially, tempered of course by significant expense associated with parts qualification. Memory technology has been the truly outstanding performer since it intrinsically lends itself to LSI techniques. Perhaps most important of all is the development of the microprocessor and its successor, the computer on a chip. These devices have yet to impact space in any significant manner.

What areas will be impacted soon? The guess here is that the continued proliferation of a wide variety of LSI components, coupled with an extension of commercial advances (e.g., bus-structured architectures), and new applications will result in a variety of new spacecraft architectures. Today's fundamental reliance on Von Neumann machine organization (Ca. 1946) will prove inadequate for sophisticated and complex problems. Mass storage LSI techniques will open new avenues for the system architect. On the other side of the coin, "testability" will present significant challenges. Testability and design-to-test techniques will probably evolve into separate and distinct disciplines.

What areas need to be driven? Two significant problems need a solution: radiation hardening and a wide operating temperature regime. Neither of these problems will be attacked because of commercial pressures. Space users will have to provide the incentive for solutions. Two other areas need to be driven: the search for and definition of the proper applications, and significant improvement in software productivity. No easy solution is on the horizon for either of these items.

As a matter of fact, it is possible that in-space computing must always be well behind the leading edge of technology because of the following

factors:

- o Space processing requirements are unique
- o Hardware components are derated because of the operating environment
- o There are few and demanding customers
- o Obsolescence rate - time to field a given technology, coupled with long mission life, approaches that of a computer generation life span.

What are the future requirements? Space computing and LSI technologies need further advances in

- o Still higher reliability
- o Radiation hardened/Qualified parts inventory
- o Reprogrammability
- o Higher speeds by order of magnitude
- o Non-volatile mass/bulk storage

There are several fundamental questions that need early answers. Is there a general-purpose architecture which could adapt to most mission-specific requirements? Probably not, without some quantum jump in throughput capability. Most new applications that are now being considered require sheer speed of operation to sustain throughput. However, it is possible that a distributed architecture may be useful for a particular class of problems.

Will commercial developments alleviate space parts problems, particularly with regard to radiation, temperature regime, and vibration? It does not appear likely that these problem areas will be addressed because of commercial market pressure. There is no driving commercial need.

Will space developers continue to go it alone? It is now, and has been the case for some time, that each space user develops and procures hardware without considering cooperative partnership arrangements. Possibly, the requirements are so unique that going it alone is the curse of the business.

The bottom line so far seems to indicate that, in general, adequate technology will be available for near-term requirements, and the real question is whether or not there will be a determined effort on the part of space users to apply this technology. This is not to say that there won't be some shortfall in technology unless dollars are thrown at the problems. As mentioned previously, these areas are most likely to be radiation, temperature and software productivity.

What does the future hold? Briefly, the following factors seem self-evident:

- o LSI technology will allow advanced architectures
- o Processors will move closer to the sensors
- o Architectures will probably be distributed in nature until throughput increases by several orders of magnitude
- o Processing applications will grow in number and complexity
- o Microprocessors will proliferate throughout the spacecraft
- o On-board processing will demonstrate high cost effectiveness by reducing the required ground support, by simplifying ground node configurations, and by reversing the trend of increasing ground mission operations cost and complexity

The On-Board System architecture issues are complex. We need to know how much processing can be done on board. This appears to be a strict function of budget (cost, schedule, power, weight and size) and dependent upon the application. We must trade off on-board versus ground operations by establishing firm system requirements which then allow partitioning of the problem. Partitioning, combined with technology, allow solving "bite-size" problems so that timing and sizing estimates are realizable.

After all the above things are accomplished, we need to solve the problem of getting "there". "There" being the place where we are accomplishing in space those processes which are cost effective. This is probably the toughest problem to solve. Any approach must result in a flexible solution which provides adequate design margin, room for expansion and reasonable contingency. There is no single best solution: getting there must necessarily involve reasonable evolutionary steps. All of this can be accomplished only by a dedicated, long-term development plan.

What can we conclude?

1. The "average" spacecraft computer is slow, small, application limited and old.
2. The direct impact of LSI on architecture has been, but need not be, minimal.
3. Operational considerations will be the driver which impacts architecture because of the requirement to operate in a stressed environment and the need to simplify ground stations.

Here are some recommendations, none of which are easily accomplished:

1. Identify what tomorrow's in-orbit processors should look like.
2. Identify the technology which must be driven to get there.
3. Be bold and bite the bullet; find the money; establish a plan; and set imaginative, but realistic goals.

SUMMARY OF ISSUES
AND RECOMMENDATIONS

NEW DEVELOPMENT IN MICRO-ELECTRONIC TECHNOLOGY

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. LSI Product Adequacy

Issue

Some existing Class "S" micro-circuit requirements are inadequate and/or inappropriate for LSI.

Recommendations

- Develop a set of product assurance requirements and test methods which are effective and appropriate for LSI, e.g.,
  - Visual inspection
  - Design for testability
  - Acceptance testing

2. Use of Commercial Parts

Issue

It is often cost effective to use commercial mainstream parts but such parts may not meet the low power, radiation tolerance requirements for space programs. It is important to identify a complete family of Class "S" parts for use by contractors.

Recommendations

- Identify, qualify and make available a complete family of low power Class "S" parts which are radiation hardened.
- Develop specific rad-hard parts where necessary to complete the family, e.g., static RAM, non-volatile memory, microprocessors, etc.
- Develop a set of constrained design tools that will permit supplementing this family.

3. LSI Design Tools

Issues

Limited availability of constrained design tools for LSI parts.

Recommendations

- Fund a national design center to provide approved design tools and design verification parts for all agencies and contractors.
- Establish qualified radiation-hardened sets of low power LSI building blocks including master slice gate arrays and standard cells.
- Identify a baseline process facility to build prototype parts.

4. Radiation Requirements

Issue

Radiation requirements limit the use of LSI technology in space.

Recommendations

- Establish realistic and consistent radiation requirements.
- Develop lot-sample testing techniques for hardness assurance.
- Fund programs to develop parts and processes capable of meeting the necessary levels of radiation tolerance as well as the performance and low power requirements of space missions.

5. Radiation Data Availability

Issue

JPL has gathered a great deal of data on device susceptibility to radiation, however, that data is not available in published form for use by industry and government.

Recommendation

- NASA should see to it that this valuable data base is made available in a timely fashion. When published, it should be put into GIDEP for easy access.

6. Availability of Memories

Issue

Limited availability of low power radiation tolerant static random access memories.

Recommendations

- Develop low power static RAMs capable of 10^9 RAD(Si)/sec upset and 10^5 RAD(Si) total dose.

  1K Manufacturing Technology
  4K Development
  16K R & D

- Specify and test for susceptibility to cosmic-ray induced single event upsets.

7. Availability of Microprocessors

Issue

Limited availability of radiation-tolerant microprocessors.

Recommendations

- Qualify to Class "S" and radiation tolerance requirements those microprocessors now on the SD/NASA standard parts list and those planned for that list.

- Procure small quantities of each type for qualification test by vendor and make these available to agencies and contractors after qualification is complete.

8. Packaging

Issue

High density packaging approaches are needed for spacecraft.

Recommendations

- Finalize Class "S" hybrid specications to insure hybrid reliability.

- Encourage the use of hermetic chip carrier parts build to Class "S" standards and mounted on multilayer ceramic substrates.

WORKSHOP F
CRAFTSMANSHIP WORKSHOP
AN APPROACH TO PERFECTION

SESSION F-3 MANUFACTURING READINESS AND CONTROLS

Chairman

Stan Chamberlain
Manager, Quality Assurance
General Dynamics-Convair

Transition from Design to Manufacturing	Paul Dalton Martin Marietta
Manufacturing Readiness Industry	Dick Sipe Boeing
Manufacturing Readiness Government	Ed Houston Ballistic Missile Office Norton AF Base
Control of Critical Items	John Wickham General Dynamics-Convair
Manufacturing and Inspection Software	Bill Chumbley Bell Helicopter-Textron

WORKSHOP F
CRAFTSMANSHIP WORKSHOP
AN APPROACH TO PERFECTION

COORDINATOR
MIKE BUTLER MDAC

SESSION F-1 CONTRACT REQUIREMENTS AND APPLICATION

Walt Carrion
Chief of Engineering Service Division
NASA, Goddard Space Flight Center

Introduction	Walter Carrion
Realistic Contract Requirements	Robert E. Balmat Rockwell International
Counter Productive Requirements/ Specifications	Dr. Altman United Technology
Directions and Needs in Craft Training	James P. Mitchell Bureau of Apprenticeship & Training
Barriers of Productivity	Max Lehrer, RCA
Contractor Selection/Past Performance	Colonel B. Weiss Aeronautical Systems Div. Wright Patterson AF Base
Contractor Assessment During Program Office & CAO Audits	Maj. D. Austin NASA Headquarters
Contractor/Contract Administration Office Audits	J. Rytlewski DSASR/LA

SESSION F-2 WORKMANSHIP AND PRODUCTIVITY

Chairman

Colonel Bill Bagwell
Director of Contracting and Support
AF Space & Millile Test Organization

The Personal Initiative Aspect of Craftmanship	Norm Wilson, Rockwell
Quality vs. Schedule Tradeoff	Art Haueschle Honeywell
Training for Craftsmanship	Dick Egelston Aerospace
Workmanship Standards	Jack Reberry AF, Space Division
Craftsmanship vs. Collective Bargaining	D. M. Verrastro Martin Marietta Aerospace

CRAFTSMANSHIP WORKSHOP
INTRODUCTION
SESSION I - CONTRACT REQUIREMENT
AND APPLICATION

Walter J. Carrion
Chief, Engineering Services Division
Goddard Space Flight Center

Good Morning, and welcome to the first session of the Craftsmanship Workshop. I hope everyone has come to work-not just listen, but to participate.

Our aim in the next few days is to examine how we do business together; how we can improve productivity and how industry and government can work better as a team.

Inflation and world competition is compelling us to re-examine ourselves and make improvements in order to reverse the nation's downward trend in its rate of productivity growth. The rate of productivity growth in the United States in the period 1963 to present has been the lowest of 11 major industrial nations.

Productivity Gains
Average Annual Increase In Output
Per Man-Hours In Manufacturing

Japan	10.5%
Netherlands	7.5
Sweden	7.1
Belgium	6.5
Italy	6.4
France	6.0
West Germany	5.8
Switzerland	5.3
Canada	4.3
United Kingdom	4.0
United States	3.4

Source: U.S. Department of Labor

The United States' present yearly growth rate now approaches zero. For many years America's technological superiority has enabled it to dominate the industrial market, especially in aerospace, aviation, electronic and machine tools. This too, is being seriously challenged by our foreign competitors who are receiving financial support from their governments to help turn our technological advantage to zero. Therefore, it is of the utmost importance to this nation that government and industry continuously re-evaluate itself in order to make the most efficient use of our available resources, both dollars and manpower.

Better utilization of dollars and manpower means greater productivity, more business for industry and greater technological advantage for this country to compete in the world market.

There are many factors affecting productivity. They range from unrealistic contract requirements and specifications to impractical design and manufacturing techniques, to improper workmanship standards, to lack of personnel initiations and skilled craftmanship.

In the next 3 days, we invite all of you to openly discuss with us any problems you experience that are counter productive to developing a final product. Today's agenda will be:

FIGURE 2

The success of this workshop depends on your participation.

Back home in my own Division, I hold a Round Table Discussion each month to pulse the Division to find out what is bothering the troops, where in the Division we are falling down, and what new ideas are "out there." Each Branch sends two employees (different employees each month) to the Round Table Discussion to discuss what is on their minds.

Ladies and gentlemen, I assure you, it's a eye-opener and a very effective tool in bringing to light problems I didn't even know existed. It brought to my attention things that are counter productive, manufacturing problems, morale problems, safety problems, misunderstanding of policies, misunderstanding of what is needed, etc.

I look at this entire workshop as a Round Table Discussion. However, the only Round Table Discussions that are of any value are those in which the employees come in and openly and freely participate. Just

as I tell my employees--I can't solve a problem if I don't know about it or understand it. Government/industry problems cannot be resolved unless we are all aware of the problems. So, I encourage all of you to participate in bringing to light items that are counter-productive, and suggest realistic recommendations to improve our use of the nation's manpower and dollar resources.

Our mission reminds me of the proverbial donkeys--each having their own desires.

FIGURE 3

I am positive that we are as smart as the donkeys

FIGURE 4

Let's share our resources.

FIGURE 5

Let's pull together.

and when we summarize the results of today's workshop, we will move on to greater productivity by working closer together as a team, as we better understand one another's problems.

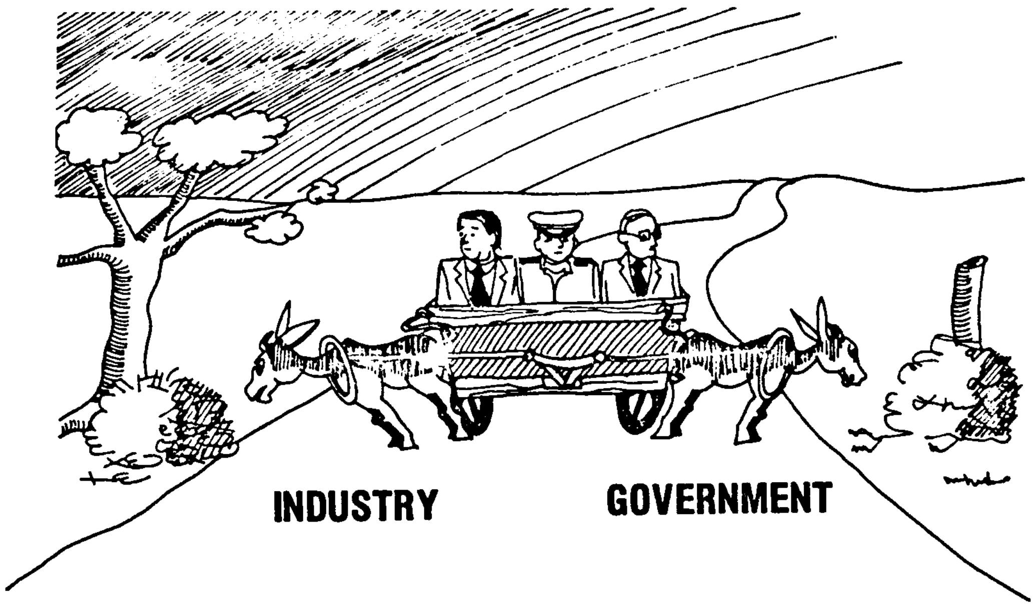
CRAFTSMANSHIP WORKSHOP

- An Approach To Perfection -

TUESDAY: Session I - Contract Requirements and Applications

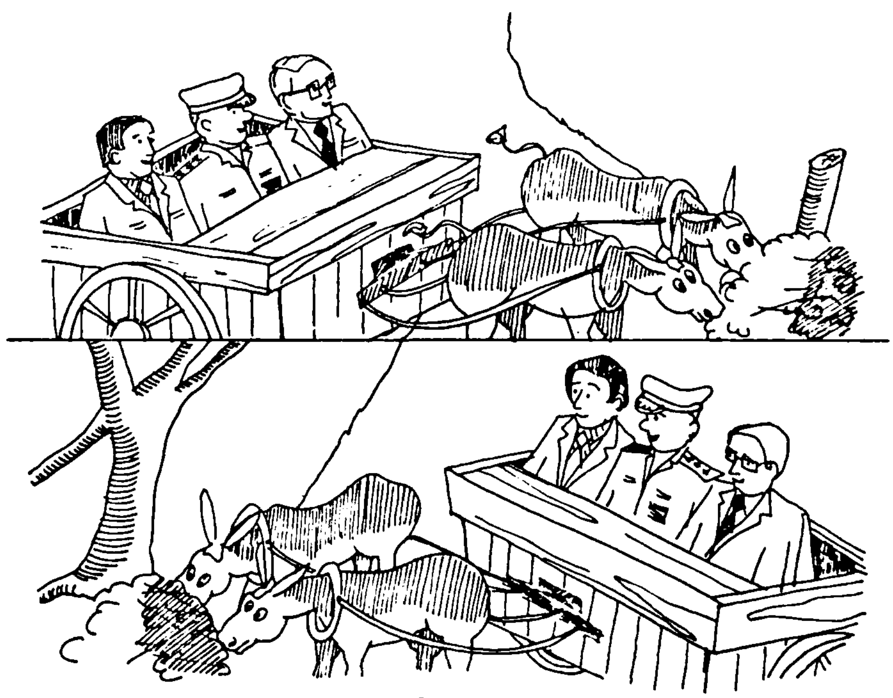
TOPICS:

0800 - 0815	A. Introduction by Chairman--Walter J. Carrion, NASA/Goddard Space Flight Center	
0815 - 0845	B. Realistic Contract Requirements • Specific Workmanship Requirements • Workmanship Requirement (How Imposed) - System/CI Specification - SOW Compliance • Tailoring	Robert E. Balmat, Controller Space Operations & Satellite Sys. Division Rockwell International
0845 - 0915	C. Counter Productive Requirements/Specifications • Identification	David Altman, Senior Vice President United Technologies
0915 - 0945	D. Directions and Needs in Craft Training	James P. Mitchell, Administrator Bureau of Apprenticeship & Training
0945 - 1000	BREAK	
1000 - 1130	Panel Discussion	Messrs. Balmat, Altman, Mitchell, Lehrer
	1000 - 1010 Barriers To Productivity	Max Lehrer, Division Vice President Govt. Systems Division, RCA
1130 - 1300	LUNCH	
1300 - 1325	E. Industry/Government Role in Mission Assurance • Warranties	Chester Hardy, Project Engineer General Dynamics
1325 - 1350	F. Contractor Selection • Past Performance	Col. Bernard Weiss, Deputy for Contracts & Mfg. Aeronautical Sys. Divison Wright-Patterson Air Force Base
1350 - 1445	G. Contractor Assessment During Program	
	1350 - 1415 Program Office & CAO Audits	Maj. David Austin, NASA Headquarters
	1415 - 1445 Contractor/Contract Administration Office Audits	John Rytlewski, Quality Assurance Staff Specialist, DCASR/LA
1445 - 1500	BREAK	
1500 - 1630	H. Round Table Discussion	
1630 - 1640	I. Closing Remarks	Walter J. Carrion, Chief, Engineering Services Division, Goddard Space Flight Center



EACH HAVE THEIR OWN DESIRES

Fig. 3



LET'S SHARE OUR RESOURCES

Fig. 4

AD-A152 733 PROCEEDINGS OF INDUSTRY/SPACE DIVISION/NASA CONFERENCE AND WORKSHOPS ON M..(U) SPACE DIV LOS ANGELES AFS CA 02 MAY 80 5/8

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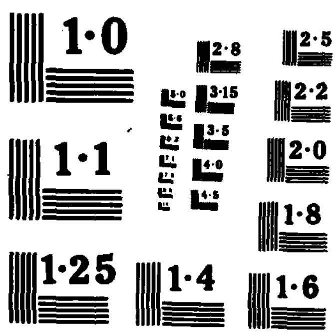
1·0
2·8
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1·8
1·25
1·4
1·6

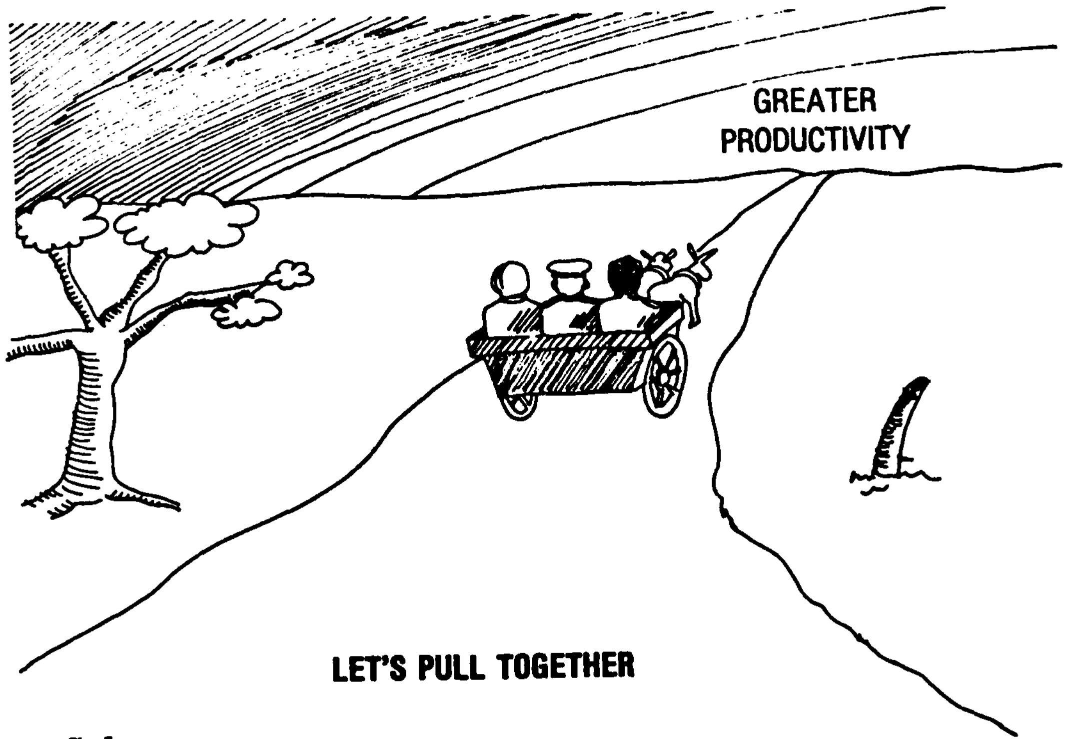


Fig. 5

REALISTIC CONTRACT REQUIREMENTS

Robert E. Balmat

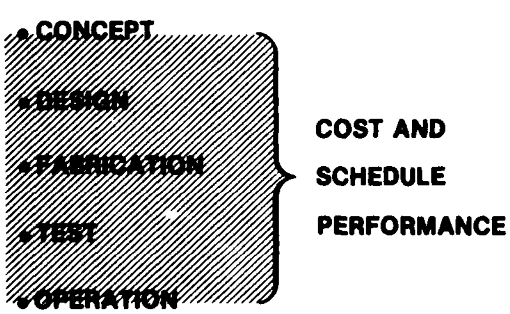
The presentation will discuss contract implication for mission assurance. The discussion will explore issues dealing with the contracts statement of work, schedule, human resources, facilities and equipment, financial resources, management emphasis and communication effecting mission assurance. Mr. Balmat's comments are drawn from current program experience on NASA and Air Force Systems Division (AFSD) spacecraft programs and observations of trends in today's business climate viewed from the perspective of a prime contractor whose mission assurance motives ultimately lead to a profitable and health business.

ACQUISITION PRACTICES

IN SUPPORT

OF MISSION ASSURANCE

ELEMENTS OF MISSION ASSURANCE



ACQUISITION FACTORS

- PROGRAM STRUCTURE
- SELECTION PROCESS
- CONTRACTUAL ENVIRONMENT
- PROGRAM EXECUTION

ACQUISITION OBJECTIVES

- REALISTIC PROGRAM
- COMPETENT CONTRACTOR
- SOUND PROGRAM EXECUTION

REALISTIC PROGRAM

- REAL "CUSTOMER"/REAL NEED
- ADEQUATELY DEFINED SOLUTION
- APPROPRIATE PERFORMANCE SPECIFICATIONS
- COST EFFECTIVE AND AFFORDABLE
- REALISTIC SCHEDULE

COMPETENT CONTRACTOR

- DESIGN CONCEPT
- TECHNICAL CAPABILITY
- MANAGEMENT
- COMPETITIVE PRICE
- MOTIVATION

SOUND PROGRAM EXECUTION

- CONTRACTOR PERFORMANCE
- GOVERNMENT PROGRAM MANAGEMENT
- PRODUCTIVITY

CONTRACTOR'S OBJECTIVE

EQUITABLE RETURN ON INVESTMENT

- RISKS
- INVESTMENT
- ALTERNATIVES

PROFESSIONAL REPUTATION

MAINTAIN LONG TERM BUSINESS PROSPECTS

OBJECTIVES

GOVERNMENT	INDUSTRY
• REALISTIC PROGRAM	✓
• COMPETENT CONTRACTOR	FAIR RETURN
• SOUND PROGRAM EXECUTION	
• GOVERNMENT	✓
• CONTRACTOR	✓

SOME PROBLEMS IN PRACTICE

REALISTIC PROGRAM

- STATEMENT OF WORK
- SCHEDULE

COMPETENT CONTRACTOR

- CONTRACT STRUCTURE
- PROFITABILITY

SOUND PROGRAM EXECUTION

- PROGRAM MANAGEMENT
- PRODUCTIVITY

SOME PROBLEMS IN PRACTICE

ISSUE

- INADEQUATE STATEMENT OF WORK

OBSERVATIONS

- INSUFFICIENTLY SPECIFIC
- CONTRADICTORY

SOME PROBLEMS IN PRACTICE

CONSEQUENCES

- INACCURATE BIDS
- INACCURATE BUDGETS
- SCOPE NEGOTIATIONS
- PROGRAM DELAYS
- JEOPARDIZED MISSION

SOLUTION

- MANAGEMENT EMPHASIS
- DRAFT RFP'S

SOME PROBLEMS IN PRACTICE

ISSUE

- UNREALISTIC SCHEDULES

OBSERVATIONS

- UNFORESEEABLE REQUIREMENTS
- RFP DELAYS
- LACK OF PLANNING
- LENGTHENING LEAD TIMES

SOME PROBLEMS IN PRACTICE

CONSEQUENCES

- MISSION RISKS
- HIGH RISK CONTRACTS
- HIGHER COSTS

SOLUTION

- PLANNING
- LONG LEAD PROCUREMENT
- AUTHORIZED INVENTORY COMMITMENTS

SOME PROBLEMS IN PRACTICE

ISSUE

- INAPPROPRIATE CONTRACT STRUCTURE

OBSERVATIONS

- FIXED PRICE VS. COST TYPE
- GEN. SLAY INITIATIVES
- CONTRACTOR CONSIDERATIONS
  - RISK VS. POTENTIAL RETURN
  - INVESTMENT REQUIRED AND INTEREST EXPENSE
  - ALTERNATIVES AND CAPACITY LIMITATIONS

SOME PROBLEMS IN PRACTICE

CONSEQUENCES

- FEWER BIDDERS
- GREATER MISSION ASSURANCE RISKS
- HIGHER BIDS

SOLUTION

- USE COST-TYPE CONTRACTS WHERE APPROPRIATE

SOME PROBLEMS IN PRACTICE

ISSUE

- CONTRACTOR PROFITABILITY

OBSERVATIONS

- GOVERNMENT BUSINESS MUST COMPETE
- RISK AND INVESTMENT
- RECENT DEVELOPMENTS INCREASE RISK
  - INTEREST RATES
  - FIXED PRICE CONTRACTS
- LIMITED UPSIDE POTENTIAL

SOME PROBLEMS IN PRACTICE

CONSEQUENCES

- LOWER RELATIVE ATTRACTIVENESS OF GOVERNMENT BUSINESS
- REDUCED EMPHASIS BY DIVERSIFIED FIRMS
- REDUCED INVESTMENT

SOLUTION

- APPROPRIATE CONTRACT STRUCTURE
- AWARD AND INCENTIVE ARRANGEMENTS
- LIQUIDATION PROVISIONS

SOME PROBLEMS IN PRACTICE

ISSUE

- PROGRAM MANAGEMENT

OBSERVATIONS

- INCONSISTENT AND UNTIMELY PROGRAM DIRECTION
- CONTRADICTORY PROGRAM DIRECTION
- INFORMAL OR DELINQUENT PROGRAM ADMINISTRATION
- LOSS OF MISSION/SOW INTEGRITY

SOME PROBLEMS IN PRACTICE

CONSEQUENCES

- DELAYS
- HIGHER COST
- POSSIBLE LOSS OF PROGRAM
- CONTRACTOR/CUSTOMER CONFLICT

SOLUTION

- STRONG, UNIFIED CUSTOMER PROGRAM MANAGEMENT
- MISSION - ORIENTED PROCUREMENT

SOME PROBLEMS IN PRACTICE

ISSUE

- FORCES AFFECTING PRODUCTIVITY

OBSERVATIONS

- LEGISLATED SOCIAL REQUIREMENTS
  - DIRECT OPERATIONAL INEFFICIENCIES
  - DIRECT COST IMPACT
  - ADMINISTRATIVE EXPENSE
- FUNDING BELOW EFFICIENT LEVELS
- WAGE CONTROLS
- CONFLICTING OR OVERLAPPING GOVERNMENT REQUIREMENTS

SOME PROBLEMS IN PRACTICE

CONSEQUENCES

- HIGHER COST
- PROGRAM DELAYS

SOLUTION

- MULTI YEAR FUNDING
- ?

SUMMARY

MISSION ASSURANCE IS AFFECTED BY

- PROGRAM STRUCTURE
- SELECTION PROCESS
- CONTRACTUAL ENVIRONMENT
- PROGRAM EXECUTION

GOVERNMENT AND INDUSTRY OBJECTIVES ARE SIMILAR

GOVERNMENT	INDUSTRY
• REALISTIC PROGRAM	✓
• COMPETENT CONTRACTOR	FAIR RETURN
• PROGRAM EXECUTION	✓

OPPORTUNITIES FOR IMPROVEMENT

PROCUREMENT PROCESS

- PLANNING
- STATEMENT OF WORK
- SCHEDULE

CONTRACTOR DISINCENTIVES

- RISK
- INADEQUATE RETURNS

PROGRAM EXECUTION

- STRONG, CONSISTENT GOVERNMENT MANAGEMENT

PRODUCTIVITY INHIBITORS

CONCLUSION

ACQUISITION PRACTICES CAN ENHANCE MISSION ASSURANCE

- REALISTIC AND WELL DEFINED REQUIREMENTS
- REASONABLY ATTRACTIVE BUSINESS OPPORTUNITY
- STRONG MISSION ORIENTED PROGRAM EXECUTION

SOME FACTORS ARE BEYOND OUR CONTROL

OPPORTUNITIES ARE REAL

COUNTER-PRODUCTIVE PRACTICES IN PROCUREMENT

David Altman
Senior Vice President-Technical
Chemical Systems Division,
United Technologies

It is a privilege to address this conference on improving mission success because of its great importance to the aerospace business in a period of declining purchasing power and tight budgets. I also welcome the opportunity to express some personal convictions on the subject which have evolved over three-plus decades in this sometimes unpredictable but always exciting business.

To start out with fundamentals, a successful procurement can be defined as one in which the product performs as intended within the specifications, and at a reasonable cost. When viewed from this simple definition, I can't help but be impressed with the overriding significance of the technical aspects of our aerospace programs and of the numerous cases of highly publicized overruns and schedule delays resulting from performance failures--beyond the level of reasonable expectation. What I would like to consider on this occasion is the degree to which both practices and attitudes in the procurement process can influence the effectiveness in obtaining a reliable product that assures mission success.

I would like to address some of the more fundamental deficiencies that frequently occur during the procurement process, both in contractor selection and in program monitoring. Most of these deficiencies are really matters of attitude and state of mind rather than of action, but are nevertheless the result of counter-productive practices.

Obviously, if the procurement process has selected the "right" contractor with the right design, the chances are much better that the contract will be successfully performed. The challenge, therefore, is how to select the "right" contractor and, more important, since that is not always possible in practice, what are the other actions that should be taken so that an acceptable product, which is affordable, will be delivered with an "average" contractor. Since one-half of our industry is composed of "average" contractors, this becomes an important challenge.

Second Source or Backup Contracts

In reviewing some of the major programs that have suffered from severe overruns due to technical difficulties, I am impressed with the fact that, although procurement may have made the best contractor selection based on the data available at the time, an effective means of assuring mission success would have been to purchase insurance in the form of a backup contract, i.e., second source. This approach is particularly important where there are critical subsystems pushing the state-of-the-art. Dual contracts for such critical subsystems should be carried through critical design review or to that point where further technical risk appears minimal. Several early procurements have employed this approach, one example being the Minuteman missile. An important prerequisite is the ability to identify a high risk subsystem which has the capability of being a show-stopper. Even when such critical areas are identified, the pressures in the current political climate are enormous to stay with only one contractor because of the apparent cost savings in the near term. A dollar saved now is more important than three or four dollars spent in two years. But is it? We talk about life cycle cost, but are we willing to abide by the conclusions of such an approach? Despite our conviction of its fundamental correctness, we usually rationalize the apparent low cost, because it is easier to sell.

Fear of Failure

The desire to have development programs that are devoid of "failures" has become more and more acute in recent years for many reasons, not the least of which is the increasing tendency to conduct development efforts in a "fishbowl" where an experimental failure in a <u>development test</u> is associated with a <u>deficiency in the program</u>. This situation is symptomatic of a fundamental misconception of how a development program in a high technology area should be run. Where

there are no "failures," even incipient ones, we rob ourselves of that critical knowledge of the boundaries of safe and reliable operation. Indeed, a development program without failures bears considerable scrutiny, and should be viewed with more than a little suspicion. I recall some 15 years ago when visiting the engineering manager at Pratt & Whitney, we discussed his philosophy in engine development. When I asked him how things were going, with a worried expression he told me he had considerable concern over an engine in development because in the first 40 engine tests, there were no failures, giving him a great feeling of apprehension. As a result, he was planning to expand the operational conditions to create at least an incipient failure to bolster his confidence. This engine, incidentally, has since had a very successful operational experience.

Perhaps the most distressing aspect of the fear of failure during development is the psychological impact on both the program managers and their superiors which inhibits the effective conduct of the program. All development efforts, expecially those involved in advancing the state-of-the-art, will experience test failures. If the contingency of having a failure is not planned, a frenetic atmosphere not conducive to a clear, rational approach needed for the solution will result if a failure occurs. Many failures are due to contractor deficiency, but more frequently, they result from lack of proper planning provoked by real or imagined competitive pressures during negotiations when cost considerations are paramount. The fear of failure has also been exaggerated by the short duty tour of government program managers whose personal careers could be damaged by a program which has the "appearance" of failures.

Another distressing feature of the fear of failure is the inhibition it creates in pursuing innovative and aggressive approaches in new technological areas, historically the cornerstone of our national growth. We need to rethink our approach to development programs and encourage an attitude that permits us to advance the technological barriers by openly recognizing that development "failures" must accompany excursions into areas bordering on the unknown.

<u>Bid Cost Versus Technical Excellence</u>

All of you have undoubtedly had discussions on this well-known subject of the relative significance of technical excellence versus promised cost during the award of a program. On this issue, I would like to restrict my comments to development-type contracts, especially those of high technological content. A common misconception with some procurement people is that, if the group proposals are "technically acceptable," the only other discriminator is the cost. Since a technically unacceptable proposal usually requires an obvious deficiency, the technically acceptable field can have a wide spread of technical capability and with no further discriminant placed on the so-called technically acceptable proposals, a disproportionate emphasis is placed on cost. The procurement is frequently reduced, in a cost-reimbursement-type contract, to selecting the lowest "promised" cost. All of the forces that bear on the so-called cost competition tend to artificially force the cost down. The budgeting process does, competition does, the Government negotiator does, even the regulations do, as there are no sanctions against underbidding, only against overbidding. There are fines and penalties for intentionally overbidding (by overstating cost elements) but only when the underbidding is extreme is a potential contractor thrown out for incredible costing.

As the not-so-surprising result of this situation, major development programs frequently suffer serious overruns. The underbid program is then performed in an environment that fosters unreasonable short cuts and insufficient contingency for anticipated problems. The result is usually a program costing more than one which is properly costed initially.

What can be done to reduce the hazard of program failures due to unrealistic low bids? Eliminate or at least modify those practices that generate undue emphasis on bid cost rather than on quality. In particular, a much more restricted use should be made of best and final offer procedures which tend to reduce the competition to an auction.

As a final comment on this important subject, the customer must be wary of not contributing to an "unreasonable" program by his actions during a competitive negotiation. During this phase, the relentless pressure on the contractor when caught up in the competitive atmosphere is to reduce price and promise more work at a higher level of performance. The result is usually an overrun and delayed program due to technical difficulties.

Contributing Issues

In addition to these three primary issues, I would also like to comment on several secondary practices that can lead to inefficiencies in the conduct of a program. These have to do with both excessive management and direction of a program, a chronic contractor complaint. I will say at the outset that such practices have arisen for legitimate reasons in programs where the contractor was in difficulty. However, as is characteristic in a bureaucratic system, these practices become institutionalized with the result that they are frequently exercised where the intended benefit is more than offset by the inefficiency that results from technical management attention being diverted from areas of greater importance.

One of the counter-productive practices I've noted is a tendency toward premature commitment to the "illities." The early phases of a major development program represent a sensitive period when maximum technical and management attention should be focused on establishing the optimum technical baseline design. It is well known that major system programs are frequently preceded by an advanced development phase, the purpose of which is to demonstrate and validate a technical approach and organizational competence to carry out the program. Such contracts are usually unfettered by the "illities" associated with full-scale development, such as maintainability, reproducibility, human engineering, and configuration management. This approach is a proper one since the maximum attention can now be placed on technical concept and hardware producibility with changes made as required within a reasonable cost. Carrying along the same argument, when full-scale development is initiated, full implementation of the "illities" should be avoided until some reasonable point, such as the critical design review. This practice would permit concentrating the available resources on the most important aspects of the program in the early phases when the designs are set, to optimize both the probability of mission success and cost effectiveness.

Another area in procurement that could bear modification is overspecification of the product. This comes about in two ways; one by the use of irrelevant specifications which is usually due to the perpetuation of requirements that are frequently inapplicable; the second is excessive specifications which lists not only the performance requirements but also how to achieve them. There has been some improvement in the latter category the past few years, but when overspecification appears, it robs the program of the experience and innovativeness of the contractor by limiting the degree of freedom in his design approach. The message is: Specify the end result, not how to attain it!

Another deterrent in effectively conducting development programs is overmanagement of the contractor. This practice is sometimes innocently initiated under justifiable circumstances when a particularly difficult problem arises, especially at the leading edge of the state-of-the-art, legitimately requiring additional aid, or when the contractor is ill-equipped to handle an unanticipated problem. However, from this understandable origin has sprung a more widespread practice, which unfortunately has all the earmarks of empire building. The sad outcome in the latter case is that in the absence of real problems, the "overmanagement" becomes engaged in overzealous attention to details, and the writing of more specifications, all of which saddles the contractor with using precious technical time to respond. Dare we suggest that the Government is occasionally overstaffed in some areas? I know of at least two instances when the number of overmanagers exceeded the workers!

In closing, I would like to summarize the changes in procurement practices

that I believe should be made to improve mission success. Among the more significant are:

First: Purchase insurance in the form of second source or back-up programs for all critical subsystems that could be show-stoppers in major development contracts.

Second: Eliminate the paranoic reaction to reasonable failures that occur during development. A certain amount is normal, healthy and necessary to place a confidence level on the product and consequently on mission assurance. Persistence of this fear can only lead to a deterrence in pushing the state-of-the-art in technology and relegate us to the position of a second-rate power.

Third: Reduce the significance of bid cost as a factor in awarding development contracts and institute additional means to evaluate technical competence such as the recent initiative concerned with past performance.

And finally, we should not reduce our efforts to modify practices and requirements that place an undue burden on the contractor and deflect his attention from more critical areas. These areas include a premature commitment to the "illities," overspecification and irrelevant specification of the product, and excessive monitoring of the contractor during the conduct of the program.

In closing, I recognize that the procurement process is a difficult one that has evolved over many years of practical experience, but still requires the exercise of judgment. I know there are retorts to each of the criticisms discussed, but I believe that improvement in the system can best come from uninhibited open discussions of this type.

Needs and Directions in Craftworker Training

James P. Mitchell
Administrator, Bureau of Apprenticeship and Training

Technological change has been with us since the discovery of fire and the invention of the wheel. In 1945, Arthur Clarke, the author of "2001" and other science-fiction works, wrote an article suggesting the possibility of synchronous satellites. In 1957 the Russians launched the first satellite; and in 1962, NASA launched the first communications satellite, Telstar. In 1963 we had Arthur Clarke's first synchronous orbit satellite, Syncom, an ability essential to low cost satellite communications of today. There is little question that the pace of change has quickened in the last quarter of this century. With increasingly complex machines, widespread application of computers, modular fabrication in many fields, industrial robots, sophisticated information processing, electronic teaching, and more in an almost endless list, it is clear that the redesign of work is impacting and transforming both blue collar traditional craft and production jobs and white collar and professional activities as well. And, it is increasing, not lessening, dependence upon the worker who has mastered the broad range or family of related task skills that make up a "trade," who understands "why" as well as "how," who demonstrates a maturity of judgment that is the mark of a craftworker able to translate into reality the vision of the scientist and design of the engineer.

<u>The Employment Outlook or Demand for Craftworker</u> The BLS model for its employment projections uses four major groups in which occupations are divided: (1) white collar workers in professional, technical, clerical, sales, managerial jobs; (2) blue-collar workers in craft, operative, and laboring jobs; (3) service workers; and (4) farm workers. White-collar workers, the largest group, now represent about one-half the labor force, exceeded in number the blue-collar group in 1955, and has experienced and will continue to experience the highest growth rate. Blue-collar workers have grown at a slow rate, somewhat below that for service workers, and farm workers continue a decline beginning with the 1950's. Table I (See attachment), gives employment data for these four occupational groups for 1976 and as projected for 1985.

Within the blue-collar group, craftworkers will increase from 11,278,000 in 1976 to 13,700,000 in 1985 a percentage change of 21.6% which compares with 19.2 % change for all groups. Construction occupations, mechanics and repairers will account for about two-thirds of the gain.

Employment growth is only part of the demand side of the equation. The need to replace workers who die or retire is expected to produce nearly twice the jobs as employment alone. In addition to work separations, the transfer of workers between occupations is an important factor in occupational mix. The Bureau of Labor Statistics estimates of job openings from growth and replacement for the four major groups is shown in Table 2 (see attachment) and graphically in Chart I (see attachment). The net craftworker demand over the period, assuming an equal annual rate, will range between 500 to 600,000 openings annually.

<u>Supply and Training of Craftworkers</u> Over simplified, the potential supply of workers for any occupation consists of persons already employed in that field plus individuals available from other sources. These may include first time labor market entrants, persons completing training programs specific to the occupation, completors from related fields, qualified persons employed and transferring, unemployed, immigrants, and persons not in the labor force. For many occupations that require formal training, adequate analyses of supply are impossible since only limited data

on training completions and entry rates are available.

Private enterprise engages in training and education to meet various business needs: (1) to train new employees, (2) to improve employee performance in present jobs, and (3) to upgrade employees for new jobs and responsibilities including replacement needs.

With respect to skilled occupations the three on-job training paths are (1) apprenticeship, (2) structured on-the-job instruction, and (3) learning by observation and exposure or doing. Apart from a limited 1975 mail survey of employer training in about 5,000 establishments for 14 occupations in 4 metal working industries conducted by BLS, no comprehensive data on training within American industry is available. The limited survey indicated about 15% of the establishments provided structured training for skills with a high incidence of apprenticeship.

Formal programs of **apprenticeship** **recognized** by the Bureau of Apprenticeship and Training or a State apprenticeship agency are an important source of new craftworkers and one for which we have data. No estimate is available on apprenticeship outside the system which today has a formal enrollment ("registration") of more than 300,000 apprentices in over 800 occupations. Last year some 130,000 new enrollments or indentures were obtained and completions were about 54,000. Registered apprenticeship is highly developed in the construction industry, yet even in this field, according to best estimates, only 40% of the skilled construction workers learned their job through formal training. Predominately in the private sector and for occupations in the blue-collar group, formal apprenticeship is gradually extending its base to include occupations normally found in the white-collar category, in government and in the uniformed military service. About 56% of registered apprentices are in construction, 24% in manufacturing, and the balance in all other industries. Roughly the same proportionate distribution prevails with respect to completions.

It is quite evident that formal apprenticeship in its present configuration, cannot be relied upon to meet BLS projected new craftworker needs. The annual rate of 500 to 600,000 such workers needed is more than nine times greater than the current annual output from the system.

Issues and New Directions — As a form of craft training, apprenticeship has strong conceptual advantages. By its users, it is held to be the least costly, most effective method for the development of highly skilled workers in the shortest time span. Why then has the system failed to become the universally accepted method for skilled worker development? While the question may not be satisfactorily answered, the search reveals probable causes and raises issues with respect to development of the Nation's skilled worker resources.

Public Policy — While apprenticeship is a historic institution, public policy in apprenticeship is of relative recent origin. The National Apprenticeship Act is dated August 1937, and was proceeded by specific apprenticeship legislation in the two States of Oregon and Wisconsin. The Federal Act simply states that it is in the public interest to develop skilled workers through apprenticeship, authorizes the Secretary of Labor to establish standards for the welfare of apprentices, encourages the States to take similar action, and authorizes appointment of advisory committees. An advisory committee was appointed and it functions today as the Federal Committee on Apprenticeship. Twenty-nine States, District of Columbia, Puerto Rico and the Virgin Islands have enacted apprenticeship legislation. About one-half the States have an operating agency with staff.

The language of the National Act is hortative. The program is advanced by promotion and persuasion. No subsidy accompanies registration. There are no "grants-in-aid" to State apprenticeship agencies.

Programs of apprenticeship meeting standards published by the Secretary are "registered" either directly with BAT in 21 States or the State agency in the remainder. Registered programs and their sponsors are subject to Equal Opportunity Regulations, 29 CFR 30.

Expanding the System In an effort to expand the program particularly into industries where it is not well represented, a number of initiatives have been mounted by Secretary Marshall. These have included:

- demonstration projects in 10 cities where small employers are banded together with government financing a program coordinating - administrative staff. No training subsidies are provided;

- demonstration projects in 7 locations to directly link high school seniors prior to graduation into an apprenticeship position. A partial training cost reimbursement is given the sponsoring employer;

- contracting promotional services with national organizations of business and labor for the organization to engage in efforts leading to establishment of apprenticeship among its affiliate local units. No training subsidies are provided.

In addition a variety of efforts at the local level to establish program linkages with CETA and supportive CETA financed outreach efforts for minorities and women have been undertaken.

Given the voluntary nature of the U.S. apprenticeship system, the options for substantial expansion of systematic skill training appear to be:

1. To provide financial incentives partially offsetting training costs to induce more employers to engage in training. Most employers do not view an investment in training in the same manner as an investment in capital goods. Rather, it is regarded as a high risk given the mobility of workers and employers, both in private and public sector, will generally elect to employ higher skilled and qualified workers when available. Experience with both MDTA and CETA OJT would indicate an employer's decision not to train can be reversed through subsidies. The amount and form are debatable.

2. To increase substantially the promotional effort, absent incentives, and the number of people engaged in promoting and assisting industry to establish programs. This does not necessarily mean increasing Federal staff; it suggests increasing State and private sector staff, the former through grants-in-aid, the latter through contracted services.

Early in 1979, the BAT floated for discussion purposes a listing of possible apprenticeship legislative specifications. These included:

- financial support to State apprenticeship agencies

- grants to apprenticeship sponsors

- subsidies in critical skill shortage occupations

- public work for unemployed apprentices

- tax credits for apprenticeship training

- apprenticeship in the Federal Government

- mandatory apprenticeship in Federal contracts

- emergency/disaster skill worker cadres

- presentation of historic hand skills

- tripartite industry training councils.

Prospective legislation was discussed with leaders in the apprenticeship community from both management and

labor, with the Federal Committee on Apprenticeship, with the American Apprenticeship Round Table, and various others. The response could be characterized as far less than enthusiastic and it is clear it would be most difficult to obtain industry backing for any broad-based apprenticeship legislation in the near future. Should the issue of financial support be surfaced again?

A survivor of that Christmas Tree of ideas for legislation is the notion that the Government should be a leader in the employment of apprentices wherever appropriate. The 8,000 odd apprentices in civilian employment soon to be matched by an equal number in the military, is far below the potential. We anticipate advancing again in fiscal 1982, the approach of an Executive Order requiring apprenticeship in Federal employment where appropriate.

This has the element of mandatory apprenticeship, the second issue -

> Should the United States entertain the Western European concept of mandatory apprenticeship?

Our one experience with mandated apprenticeship or comparable systematic skill training under 29 CFR 5a during the period of April 1971 to revocation of the regulation in August 1975 does not lend support to a system of compulsory apprenticeship. While limited in application to federally assisted construction, no significant impact upon the number of apprentices could be observed.

The U.S. educational system is ill prepared to follow the European system in preparing students for entrance into mandatory apprenticeship. Especially in the larger cities, the secondary school system is releasing a high percentage of young men and women that have little to offer in the job market. The CETA system of remedial training cannot correct the deficiencies. Industry, in a mandatory system, would be faced unfairly with this burden.

Conclusion While apprenticeship and learning by doing in a structured way is almost **universally** regarded as the most effective and efficient method of developing the skills of the work force, the system is obviously being greatly underutilized.

As a form of employment as well as training, it depends upon a job availability. Any major expansion in the system not at the expense of another job holding worker, requires expansion in the economy.

Apprenticeship is not only an extension of education for youth entrants, it is a first career opportunity for many young adults, and a renewed career opportunity for many adults.

No true measure exists as to what the potential for apprenticeship is. American industry and Government alike have a training capability largely untapped. Government policies must be framed in such a way as to use that capability while at the same time recognizing the vested interest of each party: labor-management-the apprentice, and the taxpayer, in the system.

TABLE 1: Employment by Major Group

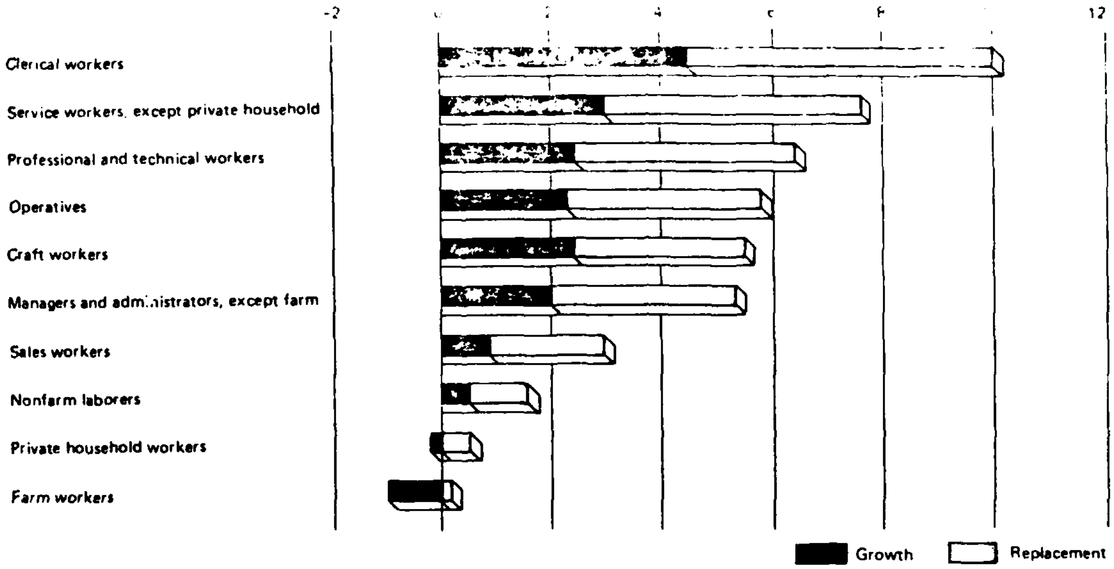
Occupational Group	1976		1985		% Change
	No.	%	No.	%	
White - Collar	43,700	49.9	53,500	51.3	22.4
Blue - Collar	28,958	33.1	34,100	32.7	17.9
Service Workers	12,005	13.7	14,800	14.2	23.4
Farm Workers	2,822	3.2	1,900	1.8	-34.1

Numbers in thousand
Source: BLS

TABLE 2

Occupational Groups	Openings 1976-1985			Projected 85 Employment
	Growth	Replacement	Total	
White - Collar Workers	9,800	15,000	24,800	53,500
Blue - Collar Workers	5,200	7,700	12,800	34,100
Service Workers	2,800	5,300	8,100	14,800
Farm Workers	-1,000	1,200	200	1,900
(in thousands)				

CHART 1: Job Openings - replacement plus growth 1976-1985 (Workers in millions)



BARRIERS TO PRODUCTIVITY

Max Lehrer

DIVISION VICE PRESIDENT, GSD, RCA

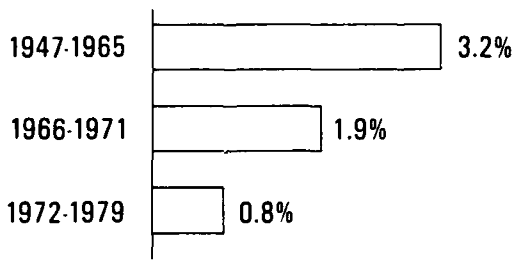
Earlier today, Walt Carrion presented some sobering figures demonstrating that the United States has had the lowest rate of productivity growth of the 11 major industrial nations. The problem is actually worse than is portrayed by the comparison of sixteen year averages of productivity growth. The dismal truth is that the U. S. productivity trends have been moving in the wrong direction ever since the end of World War II.

Here is a comparison that has been made by one of our leading economists--Pierre Rinfret.

PRODUCTIVITY TRENDS IN THE UNITED STATES

1947-1979

INCREASE IN OUTPUT PER MANUFACTURING MAN-HOUR

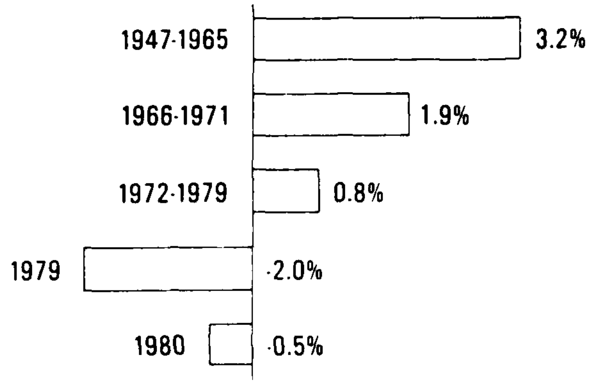


You will note that U. S. productivity increased by an average of 3.2% annually during the post World-War II period 1947-1965. During the Viet-Nam War Period, 1966 through 1976, the annual productivity increase dropped to 1.8%. From 1972 to 1979, it dropped again to 0.8%.

PRODUCTIVITY TRENDS IN THE UNITED STATES

1947-1979

INCREASE IN OUTPUT PER MANUFACTURING MAN-HOUR



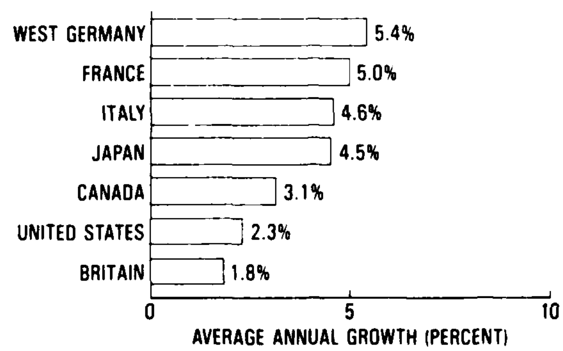
According to the President's Economic Report submitted to the Congress on January 31, productivity actually decreased by 2.0% during the year 1979. Furthermore, the Economic Report forecasts an additional decrease of 0.5% during 1980. There are many who feel that this projection is just as optimistic as the already repudiated projection that inflation would only amount to 10.4% in 1980.

In his recent second videotape, General Alton D. Slay. Commander of the Air Force Systems Command, voiced his concern over lagging U. S. productivity and used figures covering a different time frame to make his point.

INTERNATIONAL PRODUCTIVITY RANKING

INCREASE IN OUTPUT PER EMPLOYEE HOUR IN MANUFACTURING

1970-1978

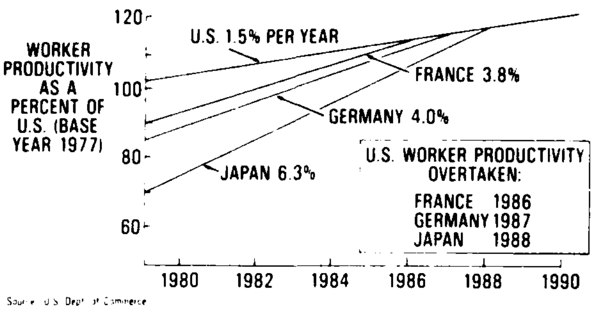


Source U.S. Dept. of Labor

Based on these figures, General Slay concluded that the U. S. would be surpassed in overall productivity by France, Germany and Japan in just a few years.

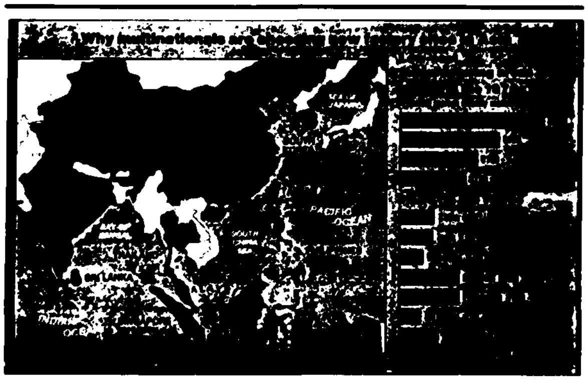
WORKER PRODUCTIVITY PROJECTIONS

(BASED ON PROJECTED GROWTH RATES—ALL INDUSTRIES)



In view of the actual decrease in U. S. productivity experienced in 1979 and projected in 1980, General Slay's projections, grim as they are, are also probably optimistic concerning the time remaining before our overall productivity is overtaken.

The threat to our future does not only arise from the highly industrialized nations of the world. During the past decade, a significant portion of our electronic components and systems have been produced in the Far East. A main attraction has been the plentiful supply of labor available at low wage rates. The average monthly manufacturing wage in the United States today, according to the Department of Labor, is $697. Fringe benefits add some 30 to 35% to our labor costs. Compare this with average monthly wages of $240 in Hong Kong, $165 in Singapore, $130 in South Korea and $110 in Taiwan.



Business Week magazine forecasts that the trend in electronics in the 1980's will be to establish new plants in even lower labor cost areas such as China, India, Indonesia, Malaysia, the Philippines, Sri Lanka and Thailand. At the same time, the established facilities in Hong Kong, Singapore, South Korea and Taiwan will be shifting from labor-intensive production to capital-intensive production. It is obvious that U. S. plants will have a tremendous challenge in competing with foreign plants equipped with the latest machinery and technology and employing a labor force whose cost is a fraction of that of the United States.

The pattern of increased competition from abroad is not confined to electronics. Our automobile industry is reeling from the inroads of foreign competition. Our aerospace industry no longer has a free-world monopoly on providing satellites and modern aircraft. Furthermore, the pressures generated by the policy to pursue NATO RSI (Rationalization, Standardization and Interoperability) will intensify free-world competition for all types of military equipment and weapons. Obviously, many factors affect the ability of U. S. industry to produce quality products at competitive prices. The single most important factor, however, is the ability and willingness of industry to invest in modern production and test facilities.

The FY 1981 Department of Defense Budget calls for an increase of 5.4 percent in real terms (that is, adjusted for inflation) and projects an average annual increase of 4.4 percent during the next four years. The Secretary of Defense has observed that "the percentage of our GNP devoted to defense has fallen from 8.6 percent to 5.0 percent since 1962." The proposed FY 1981 budget would increase the Defense share of GNP from 5.0 percent to 5.2 percent. Yet there is serious question whether this modest increase can be accomplished.

Our inability to accelerate defense production arises directly from the fact that we have allowed our industrial base to deteriorate. The problem was well described in a recent analysis made by Business Week Magazine, entitled "Why the U. S. Can't Rearm Fast"

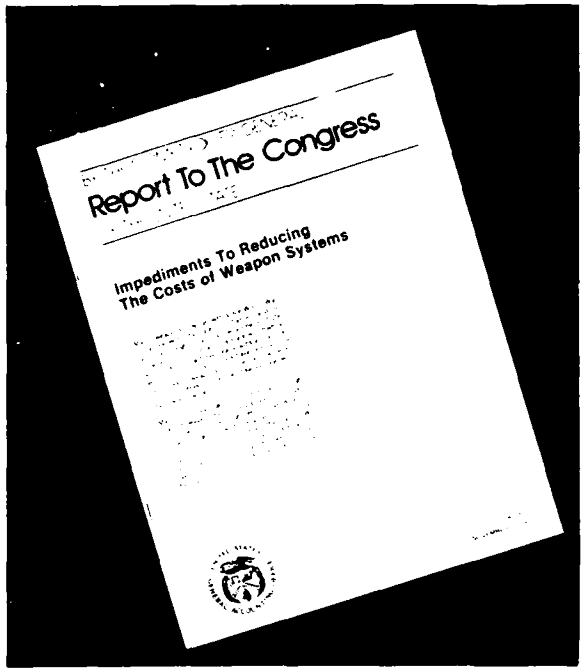
Let me quote briefly from this analysis:

> Many companies once bid eagerly on defense contracts. They built their resources to handle them but then suffered in the aerospace slump of the early 1970's and they just disappeared. And others steadfastly refuse to expand. They are concerned. . . .about having to go out and make capital expenditures to take care of peaking Government demand and then having Government say 'thanks' and walk away.
>
> Subcontractors also complain about low profits, naive procurement officers and heavy paperwork.

Finally, Business Week quotes one key aerospace executive's view of what changes would have to be made to entice companies back into the defense business.

> Of key importance would be multi-year procurement budgeting so that contractors could plan intelligently their own capital and manpower investments. Also needed . . . . is tax reform aimed at allowing more liberal writeoffs of capital investment. With such changes. . . . new machine tools, forging presses and other capital equipment would become available for defense needs.

I agree wholeheartedly with these recommendations, neither of which is new.



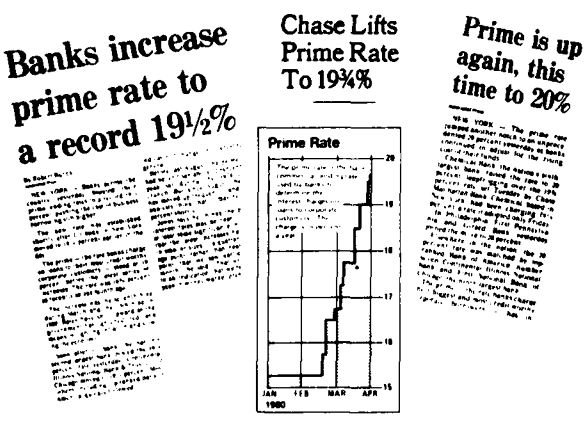
Even the General Accounting Office, in a recent report, recommended that the Congress consider multi-year funding to provide stability and take advantage of more economical production practices. The main obstacle to multi-year funding has been the reluctance of Congress to abandon any of its detailed annual reviews--and revisions--of the defense budget. However, a prudent businessman will not make binding long-range financial commitments in the face of program uncertainty. This problem is exacerbated when uncertainty is compounded by continued double digit inflation.

Going beyond statistics, clearly something is very wrong when defense supporting industry has a two-to-three year backlog and steadily increasing leadtimes and yet does not invest in new equipment.

During the Korean War, provision of an investment tax credit for projects certified by the Office of Emergency Preparedness was a simple and successful device for expanding defense-related production capabilities. Today, however, neither a tax credit nor accelerated depreciation alone will do the trick. Today we have to deal with the costly recordkeeping and other burdens imposed by the Cost Ac-

counting Standard 409. Since the Cost Accounting Standards Board has repeatedly asserted that its only concern is what it considers "good accounting practice," regardless of underlying national policy, any legislative steps taken to provide shorter depreciation lives could be undone unless the statute directed the CAS Board to let the national interest prevail over alleged "good accounting practice."

We all know that interest rates are at the highest levels in U. S. History.



The headlines that tell us that the prime rate is close to 20% don't tell the whole story. When a company borrows, it cannot obtain all the money covered by the loan. Instead, it is required to maintain a compensating balance that generally amounts to 20% of the loan. This means that a 20% nominal interest rate becomes 25%. Interest is an even greater burden for smaller companies, who generally have to pay several points over the prime rate.

These staggering interest costs erode industry profits and inhibit the investment in both production facilities and inventories required to reverse recent negative trends in productivity. When this is combined with the long-term uncertainties and increasing risks of defense procurement, it may lead many contractors to devote their efforts and resources to more profitable commercial business.

Some of the remedies to correct this situation lie within the control of the Executive Branch. Other remedies, particularly the authorization of multi-year procurement and the provision of accelerated depreciation for capital investment, would require Congressional action. In a Presidential election year, the prospects are not very bright for action on some of the fundamental changes needed. Yet the recent events in Iran and Afghanistan clearly demonstrate the urgent need to improve our readiness and capability to respond to similar challenges to our way of life.

PAST PERFORMANCE - A MAJOR CONCERN IN THE AWARD OF CONTRACTS

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In his Policy Letter # 5, dated 20 April 1978, General Slay expressed his policy that special emphasis be placed on contractor's performance on past contracts as part of the source selection evaluation process. This policy was reiterated in the well-known Policy Letter # 22 of 28 July 1978, listing specific commercial practices to be emulated by Systems Command. The guidance has now been established in the more enduring form of an Air Force Systems Command Regulation, AFSCR 550-22, dated 6 Dec 1978. General Slay's message is clear; we are to find a way to award Government business to manufacturers we can expect will deliver a quality product, on time and at the established price. With the rising costs of military equipment, the threatening world situation, and frequent evidence of taxpayer dissatisfaction, past performance evaluation must become an intrinsic part of our evaluation process.

Evaluation of a contractor's past performance is not a new requirement. The need has been around for as long as there has been an opportunity to select a single contractor from two or more competing sources for an item of defense equipment. The Contracting Officer must determine that a prospective contractor is responsible before he can award a contract. Previous efforts at institutionalizing the evaluation of past performance have not met with overwhelming success, however, and a brief review of some of these efforts might prove useful as a backdrop for the current initiatives.

From the late 1960s through the early 1970s, a number of evaluation systems existed to provide data for use in source selections. Systems Command, for example, started a program in 1956 to collect performance reports upon completion of research and development contracts over $25,000. In 1963, the Department of Defense implemented the Contractor Performance Evaluation (CPE) Program which required periodic reports during performance of development contracts of $2.M or more. The Contractor Performance Record (CPR) Program was a formal DOD program instituted in 1968 to collect data on supply and equipment contracts valued at $100,000 or more. The CPR program also required reports upon completion. Working groups were formed in support of source selections to analyze the data from these formal systems and from other official DOD, Army, Navy and DSA records, and provide a report to the Source Selection Authority. All of the formal systems have been out of existence since the early 1970s. The CPE System was abolished in November 1970 because it was not considered cost effective, and the rest followed suit shortly thereafter. Past performance continued to be a consideration in the award of all contracts, but without any formal evaluation system or procedures until 1978.

In July 1978, a decision was made by Air Force Systems Command to conduct a test of the use of past performance as a source selection criterion. This method of highlighting the importance of our experience with contractors was to be tested on both AFR 70-15 (major) source selections, and AFSCR 80-15 (R&D) source selections. The test was expected to determine:

a. Whether use of past performance as a major ranked area can be expected to produce the desired result of eliminating an offeror with unsatisfactory performance.

b. Whether use of past performance as a general consideration is adequate to produce that same result.

c. Whether use of past performance in source selection in either manner is beneficial in terms of administrative complexity, lead time, work load, and cost impacts.

d. Whether use of past performance should be a matter of predetermination at the Source Selection Authority (SSA) or equivalent level.

Fourteen Systems Command programs were selected for this test, representing source selections covering all phases of the acquisition process, from concept validation to production. Several substitutions had to be made before the test was over, and one program cancellation came too late for a substitution within the allotted time. Not all selections were completed within the time, but the data base that was obtained was considered adequate for test purposes. Dollar value of the programs varied from $200,000 to over $100.M. Three were "fly-off" competitions, two were full-scale development, eight, research and development, and one was for a validation phase. Contract type included four each CPFF and FPI, and six firm fixed price.

The results of the test which was completed in late summer 1979 indicated that evaluators want to use past performance, and that offerors want it used as well. There was agreement that, if some of the problems can be overcome, past performance has great potential. It would bring to the front of the evaluation our experience with the offeror, add to (or detract from) our confidence in his technical and schedule and price promises, and serve as a motivator during performance of current contracts.

The most difficult of the problems to be overcome is the question of devising a system that would be fair and objective, without reverting to the data bank of previous evaluation systems. The data banks didn't work. Contractors rated "excellent" accepted their ratings; others generated what General Stansberry has referred to as a "paper war", from which neither party emerged victorious. Another problem arises in evaluating an offeror without relevant past performance, but this can be resolved equitably by using a neutral rating. We must pay attention to the way we define what is relevant, because that definition, in a given source selection, will establish the kind and extent of past performance data to be evaluated. The effort taken to resolve these problems and create a viable, credible system for using past performance will be repaid in higher quality systems and equipment.

Systems Command has provided, as a modification to AFR 70-15, some definition of "relevant past performance." This definition leaves room for judgment, and will evolve as we gather experience with the new policy. For now, we will define relevant experience as experience which is:

> "work comparable to the instant acquisition, completed in accordance with a contract, recently."

It would include, for example, work in the same or a similar acquisition phase, for a similar item, or item using similar technology.

When General Slay refers to the use of past performance as a commercial practice, he is on target. Past performance is always influential in the world of lawnmowers, automobiles and jet transports, and it is often an overriding factor. Vendor rating systems are a vital part of the overall business strategy of firms. The systems in use vary in sophistication with the complexity of equipment and amount of subcontracting involved, but they all serve to exclude the unacceptable vendor, and flag the questionable one so that suitable controls can be imposed.

It is not realistic to assume that we in Government will be able to use the same basis for judgment that a commercial firm can use because of the emphasis placed on awarding to the low bidder, and the fact that, in a protest, the burden of proof would be on the Government. Every low bidder has one Congressman, two Senators, a "get well" program and 500 reasons why their poor past performance was the Government's fault or reasons beyond their control. Compounding the problem is the fact that some of those 500 reasons will be valid. We can, however, do a better job through effective evaluation programs, with positive as well as negative aspects, with continued emphasis during source selection, and with continued study to determine where changes in law or regulation are needed for improved efficiency of our source selection process.

The current Air Force Systems Command policy regarding use of past performance in source selection is stated in interim message changes to Air Force Regulation 70-15 and Air Force Systems Command Regulation 80-5, dated 1 November 1979. These changes state:

a. That past performance will be established as a specific evaluation criterion against which each element of the requirement will be measured. This means that in each "area" (such as technical, management, or cost), there must be an "item" called past performance. As an alternative, each "item" (such as hydraulics, electrical, etc., under technical) could have a past performance factor.

b. That the past performance criterion shall be equal in ranking or stature to all other criteria if all are equal, or first if ranked in order of importance. This means simply that no item, or factor, can be ranked ahead of past performance. It can be equal, or first, but never subordinate to the other ranked factors.

In addition, the regulation changes provide for verification of the contractor's submission, and for inclusion of past performance data in all documents, reports and presentations. Verification will be accomplished primarily by the cognizant plant administration activity, but this information may be augmented during the course of other source selection related plant visits such as manufacturing or other pre-award surveys.

The policy is clear. The question is, can we make it work? Can we come up with an evaluation methodology that will exclude the marginal performer from future awards and still conduct our business in an orderly manner? We think the answer is yes.

The emphasis imposed by the changes in our regulations are a step in the right direction. Accompanied by a positive attitude and determination on the part of management and a positive attitude and open mind on the part of the evaluators, the regulatory changes will work. In addition to these changes, continued emphasis on Product Assurance, including formal recognition of producers building quality products, will help foster the attitude that the Air Force is going to continue to insist on contract compliance, and is willing to reward the manufacturer that does a superior job. On the other hand, a low rating on past performance in source selections should be just one of the sanctions we must impose on the marginal producer to establish credibility on our part as to our demands for quality products. We must also make more effective use of existing procedures such as mandatory inspections and withholding of progress payments. Deferring acceptance until corrections are made rather than use of "conditional" acceptance is another seldom invoked technique. We have made some headway in these initiatives over the past two years as a result of the Quality Horizons Study sponsored by AFSC looking for ways to enhance product quality of military hardware, and other efforts, but we still have a long way to go.

The evaluation of relevant past performance, even if it was not used to exclude certain manufacturers through use of a list of "ineligible" bidders, would still be of value to the Program Office. For example, it should lead us toward more logical contract administration procedures. We need to create the flexibility in our own operations to take advantage of the information the past performance evaluation will give us, and increase inspection where indicated, for example, and also decrease surveillance where indicated. This kind of flexibility will be an offshoot of the past performance evaluation effort.

In summary, we have made a good start at institutionalizing Past Performance in source selection. While we recognize the differences in business environment between the Government world and the commercial world, we are determined to come as close as possible to the commercial world when it comes to past performance. Research is continuing in this area, to help identify and use pertinent factors that constitute past

performance information, to establish methods to assess such information, and to devise procedures to effectively acquire the information when it is needed. Emphasis will continue to be placed on quality performance in our contracting and manufacturing initiatives. Past performance has joined death, taxes and inflation on the list of things that are "inevitable."

CONTRACTOR ASSESSMENT

DURING PROGRAM, SURVEYS

DAVID J. AUSTIN (MAJOR, USAF)

MGR., QA, SPACE SHUTTLE

HQ NASA

Audits, Reviews and/or surveys are a necessary "evil" that we must live with. In many programs, these evils are neglected or minimized during the early phases of a programs life. They then tend to become corrective or punitive in nature rather than preventive. They are often called for after the fact, when a failure results in life or mission loss or cost or schedule over runs. We (NASA) prefer to be preventive and resolve potential problems before they occur rather than play the "fire fighter" role. Its obviously too late to fix a problem or system after a space system or missile failure has occurred. Until we get a Space Shuttle into orbit, space system failures will result in loss of both dollars and acquisition of needed intelligence, weather, astrological, etc., data. After we have a viable Shuttle Program some satellites will be retrievable and repairable, but others and missiles will not be. Therefore, preventive type SR&QA surveys and reviews will be the norm rather than the exception.

In NASA, we have several requirements or directive documents that provide guidance or define the use of surveys, audits and reviews. Generally, in the case of HQS conducted survey, these will be combined into one periodic Safety, Reliability, Quality Assurance and Occupational Health Review. The directives also provide for reviews at the Centers or other NASA Organizations, Contract Administration Office, and Contractor Facilities.

Today I will discuss these reviews in conjunction with the Space Shuttle Program, but other NASA Programs in general, require similar reviews.

The highest level survey, Level I in the Space Shuttle Program, consists of a Bi-Annual Headquarters Review of Level II. Level II is at Johnson Space Center. This survey is primarily to review their compliance to Headquarters SR&QA and OH Directives. The next order is a Joint Level I and Level II Review of Level III. Level III Organizations are the major subsystems; External Tank, Orbiter, SSME and Solid Rocket Booster Project Offices. These surveys are to assess the subsystem project offices implementation of Level II requirements and also to review their surveillance over prime and sub-tier contractors.

The NASA Centers perform SR&QA Surveys at the Prime Contractors on an annual basis. These surveys are fairly in-depth and, to some extent, also review the Government Resident Contract Administration Office Assurance Program. At this time the primes are also reviewed as to their surveys and controls over vendors/subcontractors.

Surveys performed at sub-tier vendors or subcontractors where more than one prime or NASA Center has an interest fall under the Joint Survey Program which is managed by Level II at JSC. On prior NASA Programs, experience has shown that suppliers manufacturing items for several major subcontractors involved on the same program have often been surveyed by each customer. In order to reduce this activity to a minimum on the Space Shuttle Program, a survey committee consisting of representatives of all the major element contractors has been established to plan, coordinate, and schedule surveys. Survey teams have been organized of all the involved customers

including the NASA Centers so that each supplier survey can be completed at the same time. These surveys are scheduled annually or more or less often as required.

All of the previously mentioned surveys tend to focus on large organizations where both dollars and resources are available for controlling the product. However, during the past several years there has been a significant decline in Government SR&QA emphasis at the lower tier levels where raw/basic materials and nuts and bolts products are produced. I believe that there has been an equal decline in Prime Contractor Surveillance at these levels also. We could cite many DOD, NASA and even FAA examples, but would rather not embarrass anyone here today. It is important, toward mission assurance, to recognize these short falls and discuss means of correcting the problem today. As an opener, I submit that the following is necessary by the Primes:

1. Identify in his purchase order the proper, realistic and adequate requirements for supplier performance.

2. Select only those suppliers or vendors who have a history of providing acceptable products.

3. Review the potential vendor/supplier prior to award, during the acquisition period and maintain receiving inspection and post acceptance records of deficiencies.

4. Require vendors/suppliers to take corrective action and follow-up for effectiveness.

By the Government:

1. Where we the Government have relaxed our surveillance efforts, request for one time selective surveys of the lower(est) tier vendors by DCAS should be considered.

2. In lieu of the above, utilization of the Joint Survey Program with minimal team members may be desirable.

Program success depends on complete control by the Prime Contractors over all vendors/subcontractors. A comprehensive surveillance program should go a long way in preventing non-conforming materials from entering end items. Associated with the Prime Surveillance Programs the Government Source Inspection System will add additional assurance, but should be applied on a selective basis as necessary.

Now that I've given you my thoughts on the need for greater vertical depth in the area of QA surveys. What are your collective ideas?

INCREASING QUALITY ASSURANCE EFFECTIVENESS

John F. Rytlewski

QUALITY SYSTEM REVIEW MONITOR,
OFFICE OF THE QA DIRECTORATE,
DCASR, Los Angeles

The Quality System Review, (QSR), a Defense Logistics Agency program to evaluate a contractor's Quality Assurance System, has indicated that several major deficiencies are common to most problem contractors. These deficiencies generate a large amount of corrective action time which is costly in terms of both money and time. Most of these deficiencies can be corrected at little cost to the contractor and, as a by-product, result in a higher quality product. Before I begin a discussion of these common deficiencies, and how to correct or prevent them, I should briefly describe the Quality System Review Program.

My primary function in DCASR, LA, is managing the QSR Program, a program by which the Directorate staff independently evaluates a contractor's Quality Assurance System. Generally, contractor candidates for the QSR program are selected because of problems relating to product quality. Therefore, in most instances, QSRs are performed in facilities which are suspect. Contractor's staff personnel are told at the entrance briefing to make use of our audit for their own benefit; use it as a free consulting service, do not fear criticism or deficiencies. The audit team members are relatively unbiased and are experienced in review methods. All deficiencies are thoroughly discussed by team members and cognizant contractor personnel.

We have found, particularly in the small operations, that management is unaware of what constitutes a good Quality System. We cannot tell the contractor how to run his facility, but we can and do make recommendations concerning methods to effect action which can correct noted deficiencies and preclude similar inadequacies.

Although most of the problems can be corrected at little or no cost, it is surprising how upper management refuses to acknowledge that there are problems, problems which can be rectified solely by changes in policy. This is especially true when management has been in the same position for a number of years and is responsible for the present inadequate policies. The following examples demonstrate several common problems and possible corrective actions:

Lack of QA Authority: We have found that in many facilities, especially the smaller ones, the QA Manager is merely a figurehead, and manages solely as a supervisor. He has no authority to ensure that the QA Svstem is an effective tool in controlling product quality throughout the facility! Quality Assurance, in this enviornment, acts only as an inspection department to screen out defective material. In this type of operations, there is usually an excessive amount of defective material submitted to Material Review, due to the lack of controls during the various manufacturing processes. Manufacturing or engineering is usually in charge and the Quality Assurance department exists only because of contractual requirements. Corrective action in this instance must be initiated at higher management levels. QA must be allowed to function as a seperate division, with the ability and responsibility to initiate, coordinate, and complete corrective actions throughout the facility whenever warranted.

Ineffective Quality Assurance Organization: As a general rule, the Quality Assurance Manager must be a dynamic and forceful individual. He must act as a coordinator between the various divisions so that corrective actions requiring joint efforts are effectively implemented. An ineffective QA organization will usually be recognized by a record of ongoing similar deficiencies. Inspection efforts will eventually become indifferent because of a lack of a follow through on corrective actions. In this example, a revitalization of the quality effort is necessary. Training, motivation, and changes of job duties or responsibilities is in order.

Submission of Defective Material to Inspection by Manufacturing: It may seem odd to say that defective material is being submitted to Inspection; you

might ask - isn't that why inspection is there - to identify deficiencies? Inspection is there to ensure a quality product; not to assist in a manufacturing workmanship training program, or to screen items submitted by obviously unmotivated or inattentive personnel.

First line manufacturing supervisors are the key to manufacturing a quality product. They are the personnel who must bear the brunt of responsibility for submitting the best possible product to inspection. Manufacturing personnel will build only to the quality level required by their supervisor. First line supervision must insist on the best possible quality from their assembly workers; the statement, "good enough," is not acceptable in a Quality enviornment. Manufacturing supervision must be trained and indoctrinated with the concept that they are responsible for the quality of the products under their cognizance. They are responsible for ensuring that their personnel receive adequate instruction and training to accomplish their assigned functions.

Inaccurate Purchasing Data: Purchasing must pass on all appropriate contractual requirements to their vendors. Lack of required tests and data for vendor supplied parts is just as defective as a missing component. Purchasing and the QA organization must work together to ensure that all applicable contractual requriements are contained in sub-contracts and purchase orders. In addition, suppliers who do not comply with all stated requirements must be compelled to take corrective action and ensure that similar deficiencies will not recur. You are paying for required tests and data; make sure you get them.

Lack of Vendor Rating System: Lack of vendor data by which you can readily anticipate vendor product quality can substantially increase your incoming defective material. Unless procedures are established by which you can identify problem vendors, Purchasing will continue to place additional orders with vendors who have proven to be inadequate. Problem vendors must initiate a program of immediate corrective action, or be replaced with more reliable suppliers.

Hopefully discussion of the preceding problem areas will cause you to re-examine your company's current policies. Correction of these types of problems will save you both time and money, and help you to produce a quality product.

PERSONAL PRIDE IN CRAFTMANSHIP

Norman S. Wilson

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SPACE SYSTEMS GROUP
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Engineering ingenuity and pride in personal craftmanship have contributed heavily to America achieving world leadership in industry. Today, Americans continue to display a wealth of engineering ingenuity in a world of mind-boggling technology. But what about pride in personal craftsmanship? It is not seen as readily and in some areas, craftsmanship has deteriorated. Why? Have people really stopped taking pride in their work? I do not think so.

A few years ago, there was a great personal pride in craftsmanship throughout the work force. For example, once in Rockwell's sheet metal department, the location of two holes in 150 small electrical junction boxes had been interchanged. Inspection personnel caught the error and returned the parts to Manufacturing to be corrected. Four mechanics came to work the next Saturday and, without punching the time clock, repaired the boxes. On the following Monday, the parts were accepted by Inspection.

Why did four people come to work on one of their days off to correct the mistake? No one would have been fired or disciplined for this error, but pride in their personal craftsmanship would not permit them to allow the boxes to remain unacceptable for use.

Another example is a loftsman who was making a template for a complex shaped fairing. As he was trimming off the excess material, he set the shear to the wrong line and cut off part of his layout. Without a word, the man put on his coat, picked up his lunch box, punched out on the time clock, and went home. Why? Making that mistake was such a blow to the man's pride that he became physically ill. When he came to work the next morning, his layout had been spliced together so that it was as good as new, and no one mentioned the incident.

Further examples include power brake operators who locked their machines into the ON position to eliminate the time wasted by the repetitive ON-OFF mode of operation. Even though this was dangero s, the operators did it because it almost doubled production. Safety regulations put a stop to this practice, but it does further illustrate personal pride in craftsmanship.

Hydropress operators, in an effort to reduce tooling costs, experimented on their own time with form dies made from various materials. They discovered that a hard wood die would form a large quantity of parts at a fraction of the cost of the conventional steel die. And manufacturing engineers have worked hours of unpaid overtime in developing new manufacturing technologies because of personal pride in their craftsmanship.

There is no doubt that Americans have taken great personal pride in their craftsmanship. Today, however, any personal pride in one's work is overshadowed by examples of declining productivity, poor workmanship, and an "I don't care" attitude. What has happened? What can be done about it?

Many factors have contributed to the decline of pride in craftsmanship. The change in the moral attitude of the country is certainly a major factor, but that subject is better handled by experts in behavioral science. Factors directly related to business are what will be addressed here.

First, craftsmanship has been stifled by too much direction and control. Because of the critical requirements of today's hardware, the increasing tendency has been to identify, through detailed step-by-step instruction, how a part should be made. Admittedly, this is necessary in some cases, but in many instances, it is not and it tends to be counter-productive. Step-by-step instruction is costly and it restricts craftsmanship. How much pride can a person have in his work when he is being told exactly how to do it? The inference is that the mechanic is not smart enough to do the job, and pride in craftsmanship will not flourish under these conditions. Part requirements should be identified and to the extent that is practical, the "how-to" left to the mechanic. The result will be increased production, reduced costs, and vastly improved morale.

The second problem is that the image of the work force has been demeaned. This has not been the result of deliberate intent but gradual erosion. Large companies in particular turn to supervision and

technical specialists for the solution to problems, ignoring the know-how and creative ability of the worker. Since the worker is seldom asked for his opinion or for his solution to a problem, is it any wonder that he feels that no one cares? And if no one cares, how can he take pride in his craftsmanship?

Another contributing factor to the lack of personal pride in craftsmanship is that sometimes there is no pride to be had. This can be caused by boredom, where the work is too simple, too repetitive, or the worker has been doing the same thing for so long that he has lost interest. This problem can be solved by reassigning the individual to a more suitable job.

An absence of personal pride can also occur when the individual does not possess the necessary skills to perform the job satisfactorily. This can usually be corrected by on-the-job training. Most people who are not adequately trained for a job will admit to their problem if they know someone is trying to help them. Quality control trend charts are a very effective tool for identifying the person with this problem. Repetitive errors of the same nature more than likely mean that some form of training is required.

Fortunately, industry has begun to recognize the problem of a lack of pride in personal craftsmanship and some noteworthy action has been taken. The Quality Circle program is a good example of how pride in craftsmanship can be stimulated and put to use. A Quality Circle is a small group of people who do similar work and meet regularly to identify, analyze, and develop solutions to work-related problems. Companies using this program are reporting impressive results in improved quality of workmanship, cost reduction, and reduced lost time. Because of its employee-oriented nature, the program provides the worker the opportunity for personal development and recognition. The result is a significant improvement in morale and craftsmanship.

Direct communication from management to the worker is a simple but very effective means of improving the worker's image, his morale, and his pride in craftsmanship. A periodic meeting that informs the worker where he fits into the organization, what is the line of command, the status of existing programs, the future business outlook, and immediate program goals makes the worker feel that he is a recognized and informed member of a team. This easy-to-implement management tool never fails to stimulate pride in craftsmanship.

In summary, I believe that pride in craftsmanship does still exist, but it needs to be revitalized. This can be achieved by the following course of action:

- Don't tie the craftsman's hands with excessive direction and control.
- Polish the craftsman's image. Give credit for a job well-done, and solicit his opinion on production problems.
- Keep the craftsman informed. Make him feel that he is a member of a team and that his role is important.
- Make the craftsman aware of quality control trends and problem areas.
- Be on the lookout for substandard performance and have training courses ready for implementation.

CRAFTSMANSHIP WORKSHOP:

Subgroup Discussions

DISCUSSION PANEL CO-CHAIRMEN:

N. S. Wilson

J. F. Otto

D. Verrastro

R. Egelston

F. I. Given

ISSUES:

- Age of Workforce
- Training
- Qualification
- Recognition

RECOMMENDATIONS:

Age of the workforce and training were treated as one subject. It was recommended that industry implement the following type plan for developing mechanics, technicians and technical staff so that retiring workers can be replaced with minimum impact:

- Coordinate with local school officials, minority leaders, unemployment offices to identify potential trainees.
- Provide training for required skills utilizing classroom and on-the-job programs.
- Direct the training along the line of career development. Encourage schools to provide such training as a regular part of their cirriculum.
- Investigate potential of training "pink collar workers" such as secretaries, to become planners, schedulers, cost analysts, etc.

Qualification was considered to be a minor problem that can be controlled by two actions:

- Update job descriptions
- Enforce demonstration of skill proficiency during probationary period

Recognition of individual performance was unanimously agreed to as an effective tool for motivating the work force. Formal programs should be developed and implemented by all contractors. Some successful techniques were identified:

- Astronaut visits
- Management talks
- Trips to launch sites
- Dinners
- Pin presentations (such as "Snoopy" type)
- Certificates of achievement.

QUALITY VS SCHEDULE TRADEOFF

Art Huschle
Product Assurance Manager
Honeywell, Inc., Defense
Electronics Division

We have all been faced with making tradeoffs between quality and schedule during our careers. Many of us can even point out some times when quality was traded off to meet schedule and no major repercussions occurred. But I am willing to bet that the majority of the time when you have traded quality for schedule, it has cost - in dollars, in performance, in customer satisfaction and/or in schedule.

One of the major reasons for having schedule problems is due to lack of or poor planning. The best way to avoid quality vs schedule tradeoffs is to improve on quality planning.

Today, I want to tell you about our technique that we at Honeywell, Training and Control Systems Center have been utilizing which has avoided many quality vs schedule tradeoffs. The technique is called "Integrated Test Planning."

INTEGRATED TEST PLANNING

<u>General:</u> Conceptually, Integrated Test Planning is a comprehensive process for mating the planning, testing and correlating of the resulting test data. A properly integrated test program defines the constraints, objectives, responsibilities and techniques for planning, implementing, monitoring and controlling the test and evaluation of the product. It provides for the orderly dissemination and utilization of test data[1]

The Integrated Test Planning process, essentially, has three phases:

1. Planning
2. Implementation
3. Reporting and Feedback.

(1)Ref: "Integrated Product Testing and Evaluation: A systems approach to Improve Reliability and Quality" by H. Gilmore and H. Schwartz, 1969.

<u>Objectives and Requirements: To ensure a timely, efficient and cost effective test program.</u> The Integrated Test Plan provides the roadmap to personnel for fulfilling these overall objectives.

The ITP is a formal document which establishes:

- what must be done
- who must do it
- when.

Gilmore and Schwartz[1] identified the following objectives which are basic to any well-planned test program:

(a) Detect engineering deficiencies as early as possible to permit suitable corrective action.

(b) Test in the most realistic operation environment available.

(c) Eliminate redundancy of test effort.

(d) Provide as much flexibility as possible to allow for inevitable changes which cannot be predicted, for example, failure, with subsequent retest requirements.

(e) Ensure that critical test items will not be subjected to excessive or unnecessary operation.

(f) Promote orderly progression from laboratory test through operational use on schedule.

(g) Optimization of test specimen cost through maximum use of all test specimens.

(h) Continuous control of test specimen configuration.

(i) Provide a basis for the correlation and utilization of test data from all sources.

(j) Permit orderly and controlled implementation of the test program with logical timing, sequencing, and interrelation of the several types of tests.

(k) Correlation of discrepancies and failure experience from test to test, but primarily from development through final acceptance testing.

(l) Orderly development and verification of requirements and procedures in parallel with the hardware development.

Honeywell's Approach: Honeywell approach is not that different or unique from the fundamentally sound approach just presented. What is different or unique perhaps is its objectives and requirements. These objectives include:

1. Early emphasis on test planning via a formal program Integrated Test Plan (ITP) and detail Test Plan Summary Sheets (TPSS).

2. Establish an organization element with singular responsibility for T&E.

3. Eliminate redundant testing.

4. Identification and early implementation of engineering investigative tests.

5. Establish a corss-reference of test requirements that tracks from the highest to the lowest hardware level.

6. Emphasize early identification of problems and their timely corrective action.

7. Consider ITP a working document; periodic updating.

These objectives provide the major theme behind a successful Test Program and that theme is:

"To deliver equipment at minimum cost, on schedule, and with minimal technical risk"

INTEGRATED TEST PLAN

Honeywell considers the following elements as basic to formation of a typical integrated test plan. It should be noted that the type of program (developmental or production) will effect the emphasis and detail contents of each section:

Typical ITP contents:

Objective	Test Support
ITP Update	Test Documentation
Organization	Schedules
Test Program	

OBJECTIVE:

- Identify major test program objectives.

- Denote type of program:

  Production:

  Emphasize detail scheduling and availability of test equipment;

  Concerned with Manufacturing Screening, Factory Acceptance Tests, Production Assessment tests; and STE Design Evaluation/ Operational Proofing Tests.

  Developmental:

  Emphasis on detail planning from lowest hardware level through to highest;

  Concerned with Engineering Investigative, EMC, Environmental Extremes, Reliability and other Subsystem (or System) level Engineering Evaluation tests prior to Operational Testing.

ITP UPDATES:

- Specify periodic updates, typically:

  - Quarterly during a production program and yearly during a development program.

- Provide updates in an Integrated Test Status Report:

- In development programs can be provided as part of monthly technical status report.

- The Status Report should include the following as a minimum:

  Brief discussion of significant problems,

  Updates of test schedules,

  List of tests completed,

  List of failures having occurred, including summary results of analyses performed and corrective action,

  Changes to ITP.

ORGANIZATION:

- Assignment of a single individual in the program organization with responsibility for the test program. He should report directly to the Program Manager and function to:

  - Implement test program plan and schedules;

  - Coordinate availability of test resources, including usage of facility support groups;

  - Provide direction in solving test problems, responsible for arriving at corrective action;

  - Advise program management of progress, schedule constraints and problems.

TEST PROGRAM:

- Clearly identify all tests, relating to the various hardware levels:

  - LRU, Major Component, Subsystem and/or System;

  - Refer to Figure 1.

  - Emphasis on setting up a progressive sequence of testing at increasing levels of assembly and environmental complexity.

- Preparation of detail Test Planning Summary Sheets (TPSS) for all test items;

  - The purpose of the TPSS is to document the test requirements, test objective, test equipment, test description, pass/fail criteria, and test schedule (as applicable).

  - Two examples are shown; both are applicable to development programs:

    Example #1: TPSS has a broader scope of usage and closely follows the elements listed above.

    Example #2: is performance oriented and in this respect is very detailed, specifying the planned methods for verifying the requirements.

  - Clearly shows all parties the intended purpose and interpretation of the test requirements. Provides some planning information (i.e., equipment, schedule).

- Types of Tests:

  Development Test Program - typically includes the following:

  - Development or Engineering Investigative (subsystem, major component, LRU - breadboards and prototypes);

  - Manufacturing Tests (system, major component, LRU):

    Receiving Tests

    Parts Screening

    Product Acceptance, including software

    Manufacturing Screening Tests.

- Engineering Evaluation or Design Verification (subsystem, and system):

  Environmental Qualification

  EMC, includes EMI, Magnetic, EMCON, EMP, etc.

  R/M Demo's

  Performance Evaluation

- Operational Testing (System)

<u>Production Program</u> - typically includes:

- Manufacturing Tests -

  Parts Rescreen

  Burn In

  Random Vibration

  Thermal Cycle

  Acceptance

- First Article Inspection/ Production Qualification (system)

- Production Assessment Tests (system)

- Design Evaluation Tests and Operational Proofing of STE.

- Clearly establish test responsibilities (Refer to attached example).

- Specify the data collection, reduction and analysis requirements. Where applicable prepare a plan.

TEST SUPPORT

- Identify Test Facilities and Equipment, including GFE.

- Personnel

- Logistics in support of System Level field testing.

- Training.

TEST DOCUMENTATION

- List all test procedures and reports that will be required.

- Procedures should provide detailed step-by-step procedures for performing test; include data requirements.

- Consider usage of Flash Test Reports:

  - Vehicle used to inform the internal engineering organization immediately on test results;

  - Format to address test purpose, parameters measured, results and impact statements as to effect on the collected data;

  - Compile within one day of test;

  - About one page in length.

SCHEDULES

- Coordinate with Master Program Schedule

- Must schedule in detail all tests including submittals of test procedures and reports

- Via the integrated test status, report and/or ITP update, process schedules should be periodically updated. Provide status and important planning information.

Integrated Test Planning will not eliminate the need to perform quality vs schedule tradeoffs. If properly done, ITP will reduce the number of tradeoffs during a program and will also prove to be an invaluable tool to assess the impact of the tradeoffs.

E X A M P L E # 1

TEST PLAN SUMMARY SHEET

TEST NO: F0001-C

TEST TITLE Reliability Demonstration Test (RDT)

TEST ITEM EDM 2 and EDM 3

PART NO. ______________________________

TEST OBJECTIVE: To demonstrate by test that the system satisfies the MTBF and MTTF requirements of the System Specification.

TEST REQUIREMENT DOCUMENT:

System Specification; R/M Program Plan; RDT Test Procedure (to be developed)

TEST DESCRIPTION:

The primary system MTBF and the MTTF requirements will be demonstrated in accordance with Test Plan III of MIL-STD-781 (sequential test, $\alpha = \beta = 10\%$, discrimination ratio 2:1); the PM/FL MTBF and Yaw stabilization MTBF will be demonstrated in accordance with Test Plan IV of MIL-STD-781 (sequential test, $\alpha = \beta = 20\%$, discrimination ratio 2:1).

TEST INSTRUMENTATION REQUIREMENTS:

VTVM, Multimeter, Oscilloscope, System Special Test Equipment, Tools for fault repair, spares and consummables.

PASS/FAIL CRITERIA:

4.2.8.3 of MIL-STD-781 for the Primary System MTBF and the MTTF; 4.2.8.4 OF MIL-STD-781 for the PM/FL MTBF and the Yaw Stabilization MTBF.

SCHEDULE: START April 1974 COMPLETE June 1974

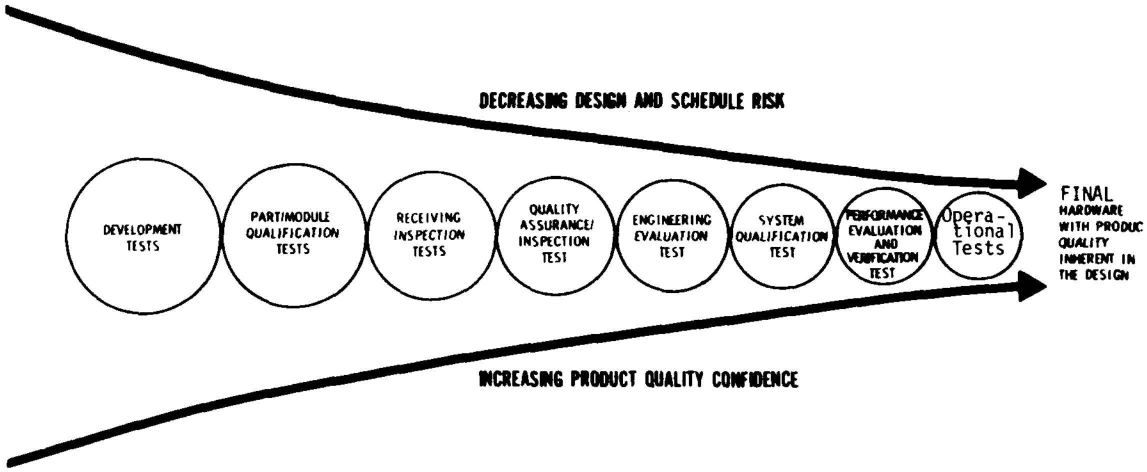


Figure 1. Integrated Test Plan Program Funnel of Testing. A program of continuous testing that reduces design risk and assures product quality

EXAMPLE #2

SEAFIRE TEST PLAN SUMMARY SHEET

TPSS NO. A-0001

DATE ______ REVISION ____

PART NAME ______ PART NUMBER ______ REVISION ______

APPLICABLE SPECIFICATION ______ REVISION ______

SUPPLIER Honeywell TEST LOCATION T&CSC

Item	Sampling: 100%				Required Manufacturing Acceptance Tests		
		Pass/Fail Criteria			OPERATING PERFORMANCE TESTS		
	Test Parameter			System Specification Para. **	Room Ambient (Final Acceptance)	During Environments*	Pre/Post Environments*
	PERFORMANCE						
1.	Interface definition:			3.1.5	--	--	--
2.	. interfaces			3.1.5.1.1	T	--	--
3.	. environmental conditions			3.1.5.1.1.4	P	P	P
4.	. input/output signal characteristics			3.1.5.1.2.1	D	--	--
5.	. shielding			3.1.5.1.2.2	D	--	--
6.	. self-test signals (BIT)			3.1.5.1.2.3	D	--	--
7.	. primary power interface	(per 4.2.1	3.3.2)	3.1.5.1.3.1.1	T (EDM A	only)--	--
8.	. director angular coverage			3.1.5.1.4.5a	T	--	--
9.	. man/machine interface			3.1.5.1.8	D	--	--
10.	. tilt compensation (and sub panels)			3.1.5.2.2	D	--	--
11.	. azimuth and elevation alignment			3.1.5.2.3	D	--	--
12.	. power	(per 4.2.1	3.3.1)	3.1.5.3	T (EDM A	only) --	--
13.	OPERATIONAL STATES:			3.2.1.1	D	C	C
14.	. OFF state			3.2.1.1.1	D	P	P
15	. STANDBY state			3.2.1.1.2	D	P	P
16.	. OPERATE state			3.2.1.1.3	D	P	P
17.	. - ready			3.2.1.1.3.1	D	P	P
18.	. - designation/slave			3.2.1.1.3.2	T	P	P

T - Test D - Demo P - Periodic Verification C - Continuous Verification

* = Verify according to room ambient (final acceptance) test method.
** = Verify in accordance with 4.2.1.3.1 of System Specification, unless otherwise specified.

TABLE 1. TEST RESPONSIBILITY MATRIX

Test Element / Test Phase	Test Plan	Site Prep.	I&C	Test Director	Equip. Operation	Org. Maint.	Data Collection	Data Analysis	Test Reports	Equipment Teardown
All MA Tests	H	H	H	H	H	H	H	H	H	H
Subsystem Environ.	H	H	H	H	H	H	H	H	H	H
EMI (MIL-STD-461)	H	H	H	H	H	H	H	H	H	H
EMP	H	H	H	H	H	H	H	H	H	H
Reliability Development	H	H	H	H	H	H	H	H	H	H
Maintainability Verification	H	H	H	H	H	H	H	H	H	H
Reliability Demonstration	H	H	H	H	H	H	H	G	G	H
Maintainability Demonstration	G	G	n/a	G	G	G	G	G	G	n/a
EMCON/EMC	G	G	H	G	G	H	G	G	G	H
ECCM	G	G	H	G	G	H	G	G	G	H
Performance Eval Test:										
Phase I	H	G	H	H	H	H	H	H	H	H
Phase II	G	n/a	n/a	G	G	H	G	G	G	n/a
Phase III	G	n/a	n/a	G	G	G	G	G	G	H
Operational Test	G	G	H	G	G	G	G	G	G	H/G

Definition of Terms: H = Honeywell; G = Government; n/a = Not Applicable.

TRAINING FOR CRAFTSMANSHIP

R. W. Egelston, P.E.
Electronics & Optics Division
The Aerospace Corporation

What is craftsmanship. Quoting from Webster's Unabridged Dictionary "it is the result we see when a craftsman does work of consistently high quality". Substituting manufacturing operator for craftsman and high reliability for high quality, we have a definition that suits our purpose.

In this paper I will first review the industry practice for developing operators, make some suggestions for improving the level of craftsmanship, and conclude by considering what has to be provided to support the operator in producing high rel hardware.

Now before we proceed with Mission Assurance 1980, you might like to look at Mission Assurance 1850!

VIEW GRAPH #1

So much for nostalgia.

When I was scheduled to talk on the subject of Training for Craftsmanship, I recalled how often "operator error" was reported as the cause for discrepancy on MRB and waiver/deviation actions, and the corrective action was, "cautioned the operator", "retrained the operator", "disciplined the operator", etc.

In a majority of these cases, it was my judgement that the real culprit was insufficient training of the operator, possibly compounded by too lax supervision.

So it seems to me, that there must be a better way to train the people who perform manufacturing and assembly operations.

Present Industry Practice

Applicants with minimum qualifications are given from one to six weeks of classroom training in an assembly school before continuing on-the-job training on the production line. The more apt trainees are sent to programs that require higher levels of competence, etc., so that practically all entrants are eventually employed. Thus there is no psychological incentive to strive for perfection.

In theory, the line supervisor takes over the trainee and structures his or her work assignments to fit the capabilities of the individual, gradually increasing task difficulty and complexity until the trainee has developed into a competent operator.

Since it requires a minimum of six months to thoroughly train an operator, it is obvious that most of the operator's skills are developed practicing on production hardware!

In practice, the supervisor may be spread too thinly to give the individual

attention necessary to make the program work as desired. Thus, as I remarked before: "operator error" results.

My remarks are not intended to indict, but rather constructively critize these training procedures and hopefully bring about improvements in "Training for Craftsmanship."

Proposed Hi Rel Operator Training

My proposal is to establish a manufacturing operations school, where all facets of hardware manufacturing and assembly are taught prior to the operator's taking his/her place on the production line. This will be a one level of competence school, program oriented to produce nothing but hi rel hardware.

The candidates for this training would be selected by industrial, psychological and physical testing for the characteristics necessary to develop into a hi rel operator, such as:

- Natural Aptitude
- Manual Dexterity
- Attitude Toward the Work
- Emotional Stability and physical capacity to perform at a high level consistently

Not all people who want to learn manufacturing operations are suitable for hi rel work.

The instructors must be outstanding in their ablility to instill the hi rel attitude in their trainees.

From the first day of training the future operators must be indoctrinated in the importance of their contribution to the end product.

Somewhere in their training they should learn what the finished product is, its importance to national security, and where their particular operations fit in the overall picture.

Examples of essentially perfect hardware should be displayed and the trainee should have enough "hands on" practice to produce hardware that approximates the samples.

This should not be a structured "X" number of hours training program, but rather flexible enough to allow attainment of near perfection before the operator works on production hardware.

The passing grade for the hi rel operator should be in the high 90's. 70% is not good enough for a hi rel program.

But, training for craftsmanship doesn't stop on graduation day. The line supervisor, takes over the responsibility of keeping the high rel attitude alive.

VIEW GRAPH #2

Now let's itemize some of the support items needed to assure manufacturing

the quality of product necessary to assure Mission Success.

TRAINING FOR CRAFTSMANSHIP

- o DESIGN FOR EASE OF FABRICATION
- o APPROPRIATE WORK STATIONS
- o COMFORTABLE ATMOSPHERE
- o DETAILED ASSEMBLY INSTRUCTIONS
- o ASSEMBLY AIDS
- o COMMITTED MANAGEMENT
- o CONTINUING INCENTIVES

DESIGN FOR EASE OF FABRICATION

The manufacturability of the hardware should be influenced as early as possible in the design stage.

If the design is such that parts placement is difficult or attachment (solder, weld, etc.) is troublesome, reliability may degrade.

APPROPRIATE WORK STATIONS

The work station should fit the operation being performed, being outfitted with necessary tools, materials, etc.

COMFORTABLE ATMOSPHERE

Lighting, air conditioning; clean room atmosphere if required; all that is needed to support the high rel attitude.

DETAILED ASSEMBLY INSTRUCTIONS

This goes with "appropriate work stations" but is so important that it must be emphasized. The details of assembly must be spelled out. What tools, or materials are to be used? How they are to be used? The assembly planning function is the bridge between the operator's skill and the finished high rel assembly. "Clean as required" doesn't cut it!

ASSEMBLY AIDS

Another item that goes with "appropriate work stations". Any jig, fixture, picture, etc., that assures proper assembly will enhance our quest for craftmanship.

COMMITTED MANAGEMENT

The high rel attitude must permeate all levels of management, but the role of the line supervisor is most critical. He is the one who establishes a coach/player relationship with the operator, and he must not be loaded with so much paperwork and/or so many operators that he has no time to supervise.

CONTINUING INCENTIVE

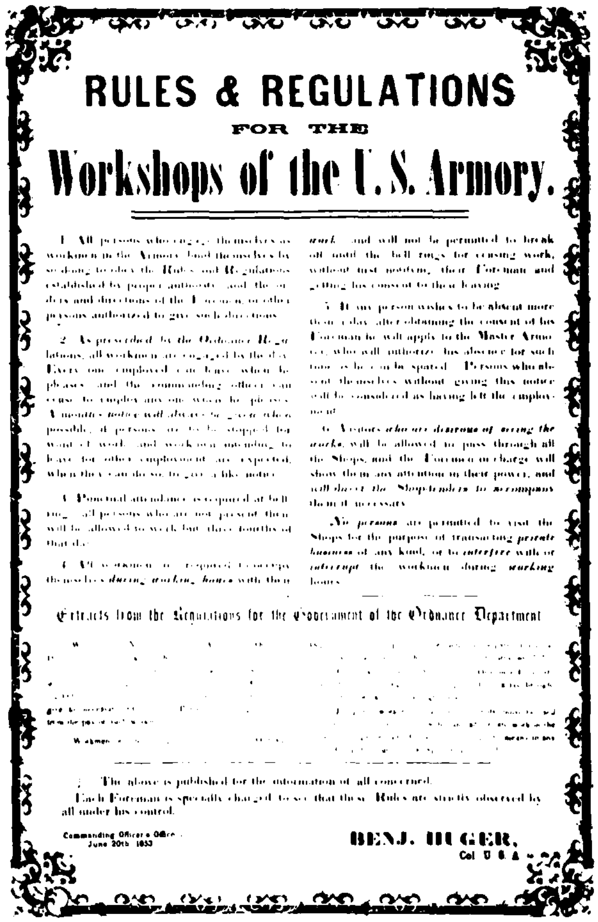
The continuing incentive for maintaining excellence is recognition of the operator's individual contribution.

SUMMARY

The elements of Training for Craftsmanship are:

- Select trainable people. Thoroughly develop their skills.
- Indoctrinate them with the high rel attitude.
- Provide the support necessary to produce high rel hardware.
- Provide continuing education and reinforcement of the high rel attitude.
- Recognize the individual's achievement and contributions.
- Motivate the operator to continue performing at the highest possible level.

In conclusion, to paraphrase a favorite saying in our industry, "Make it right the first time for lower costs and higher reliability".



RULES & REGULATIONS

FOR THE

Workshops of the U.S. Armory.

Extracts from the Regulations for the Government of the Ordnance Department

BENJ. HUGER,
Col U S A

MISSION ASSURANCE 1850

TRAINING FOR CRAFTSMANSHIP

DESIGN FOR EASE OF FABRICATION
APPROPRIATE WORK STATIONS
COMFORTABLE ATMOSPHERE
DETAILED ASSEMBLY INSTRUCTIONS
ASSEMBLY AIDS
COMMITTED MANAGEMENT
CONTINUING INCENTIVES

DEVELOPMENT OF ELECTRONIC WORKMANSHIP INSPECTION STANDARDS FOR SPACE APPLICATION

JACK D. REBERRY

STAFF QA SPECIALIST

USAF - SPACE DIVISION

The first thing that comes to mind when one hears that another military specification is being written is why? There are specifications and standards written for just about anything that can be imagined - including space application. However, as you may or may not know, the first Mission Assurance Conference uncovered the fact that though many specifications and standards having to do with workmanship have been published by the Government only a few actually had criteria that illustrated and described what was acceptable or unacceptable.

Therefore, on the fifth of March, 1979 the Air Force Liaison Panel of the Aerospace Industries Association (AIA) and the National Security Industrial Association (NSIA) met with Space Division to discuss this mutual problem. One of the chief concerns of Space Division's Commander, Lt Gen Richard Henry, was and is getting good craftsmanship (workmanship) on spacecraft.

At that meeting AIA and NSIA agreed to take on the task of developing a set of good workmanship standards that could be used to bridge the requirements between specifications and assembly drawings or instructions. Marty Adams, Rockwell International and George McGee, Martin Marietta agreed to cochair a working committee and AIA, and NSIA agreed to fund the project. It was assigned project No. 79.3.

The objective of the project was to develop and provide a coordinated set of workmanship standards that described Space Division's criteria for acceptance of high reliability electronic products. The scope of the project was to be limited to pre-installation, installation and post installation of parts used on spacecrafts and boosters, and to form the basis for a military specification.

AIA/NSIA described the project as follows:

> "A large number of documents dealing with the subject of workmanship standards have been issued by various Government agencies. Many are redundant or conflicting; many attempt to describe "how to" do a job rather than to describe criteria; some technologies have not been treated; almost every Aerospace company has their own set of standards which may or may not be accepted by the Government as adequate. This project will attempt to provide a single set of standards to be used by SAMSO for future procurements."
>
> "Maximum use will be made of line drawings and artists' renditions of specific standards with appropriate simple text to describe acceptance and rejection criteria."

The task description went further by stating that the goal would be to develop a workmanship standard that could be used by military and industry and would eliminate uncertainties that now exist in Government standards. Industry believes present Government standards are incomplete and not current with modern assembly and packaging methods.

A committee was then formed to outline schedules to accomplish the tasks, find knowledgeable workers who were willing to accept the responsibility of developing the standards, and schedule other necessary events.

The committee defined that the standards must avoid describing "how" to accomplish any specific task. To tell manufacturers and their employees how to do a job, we believe, takes away the incentive to improve on a manufacturing process; that is, to do it better, faster, or less expensive.

Instead, these standards are to only direct the inspector, assemblier or operator in deciding good from bad, acceptable from rejectable. They are to have, to the greatest extent possible, clear visual drawings or pictures, or both, and as little narrative as possible to describe the acceptable and unacceptable criteria. When known, good reference notes may also be included. The same is true for application notes. When possible, all standards should contain four examples-two acceptable-two unacceptable-arranged in decreasing order from near perfect to very bad. They should be titled PREFERRED, ACCEPTABLE and UNACCEPTABLE. There should always be one preferred and at least one acceptable and one unacceptable. Either of the following combinations should be used.

Preferred		Preferred
Acceptable	or	Acceptable
Acceptable		Unacceptable
Unacceptable		Unacceptable

All dimensions are also to be in metric.

On May 1, 1979 a meeting was held at Rockwell International, Seal Beach, CA. Present were George McGee, representing AIA; Marty Adams, representing NSIA and myself representing Space Division. The purpose of the meeting was to specifically define the areas of workmanship that would be covered by the project, select a committee to draft the standards and establish the considerations (characteristics) for each of the selected areas. Eight areas (manufacturing processes) were identified, they were:

1. Micro circuit installation.
2. Transistor installation.
3. Mounting of small chokes and transformers.
4. RF circuits (special consideration) (subsequently canceled).
5. Pretinning of component leads and removal of gold plating.
6. Definitized acceptance criteria and visual standards for printed circuit board acceptance after component installation.
7. Jumper wire installation on PCB's
8. Conformal coating.

Besides the two cochairmen, Marty Adams and George McGee, the original committee was made up of the following personnel:

G. F. Thomas	- General Dynamics
John Churchwell	- McDonnell Douglas
Charles C. Cook	- Northrop Corp
Ben E. Graves	- Boeing Aerospace Co
Herman L. Wuerffel	- RCA Corporation
Jack Janoyan	- Honeywell Avionics
Carl J. Thaler	- Lockheed Missile and Space
Iver Wahl	- Ball-Aerospace Systems Div
Jack Reberry	Space Division - AFSC
George Adams	- Northrop Electronics
Bill Coey	- Boeing
Tom Mayberry	- McDonnell Douglas
Ken Wolpers	- Honeywell
Ray Klotz	- Watkins - Johnson

Letters requesting assistance were sent to many other Directors of Quality Assurance throughout Space industry in search of experts in the eight areas. They were asked to select an expert in a specific area to work with the committee by developing a draft standard.

A meeting was conducted at Martin Marietta, Aerospace Division, Denver, CO on 13 December 1979, where all drafts of the workmanship standards were reviewed, discussed, critized, and many changes hammered out. Space Division, at that time, expressed concern and reserve at developing a standard that would appear to be allowing discrepancies; that is, developing standards that would permit some crazing and measling and using jumper wires on PC Boards. To Quality Assurance at Space Division, standards of this type would be considered as falling into the area of repair procedures.

Regardless AIA/NSIA intends to standardize, wherever possible, so that industry's workmanship (at least in space hardware) will be uniform. The Government will consider each standard on its own merit prior to converting them to military standards.

After rewriting the standards another meeting was called by the cochairman, Marty Adams and Dick Hannum. (Hannum had replaced George McGee.)

The meeting was again held at Rockwell, Seal Beach on 14 Feb 80. The committee members had done their work well because each proposed and presented standard which had been previously reviewed by them were still found to need improvement. At the conclusion of the meeting the drafts were to again be corrected. For the hard work, patience and dedication I would like to assure credit is given to all committee members who helped develop the standards with special kudos to the cochairmen.

In developing workmanship standards for space application this is just a good start. The end, I am sure, will never arrive because technology advances and one innovation, discovery or invention succeeds the next. Space Division would, however, like to develop workmanship standards for parts, assemblies and processes known to us now. Areas that have not been addressed (such as the requirements of MIL-STD-454, General Requirements For Electronic Equipment, MIL-E-8189, Electronic Equipment Missiles, Boosters and Allied Vehicles, General Specification For, and MIL-E-4158, Electronic Equipment for Aerospace Ground Equipment) need workmanship standards. The AIA/NSIA Committee felt that at this time it was more important to complete the eight areas that were selected.

MIL-E-8189 references many specifications and standards for parts, materials, and processes. Each one of the referenced specifications need a workmanship standard. Until we have standards that are used industry-wide there will continue to be variation in what is good and bad; what is acceptable and unacceptable. Of course, there will continue to be variation in workmanship as long as more than one person, company or line peforms the work because of the differences in craftsmanship.

I define craftsmanship as the training, discipline and motivation of the individuals accomplishing the workmanship. There are many good books written on all three: training, discipline and motivation. Therefore, all I will add is - the better trained, the more disciplined and the more motivated - the better people performing the work will be in making the craftsmanship look and perform the same. Especially, if they are all being trained and are working from the same specifications and workmanship standards. It is needless to say that without management's endorsement and dedication none of the controls discussed will work.

At Space Division we are working on ways to improve discipline and motivate contractor's personnel and that way is through contractual incentives. We are exploring different ways to include incentives that will directly effect the individual rather than or as well as the company. Some approaches are through award fees - part of the criteria for the successful bider will be a plan whereby the individuals working on the program will be rewarded for certain acts and thus motivated. We are also doing something about discipline of the contractor's personnel.

Through our extension of MIL-Q-9858A, SAMSO STD 73-5B, we require contractors to maintain a training program. The training program requires the contractor to certify the individuals in the areas where they have been trained. Recertification after certain lengths of time is also required. The contractor is required to identify the required skills and maintain records of the training, certifications and recertifications. We believe this program will motivate and discipline personnel.

It is the Government's policy to reduce or elimiante, where possible, specifications and standards.This is especially true where specifications include by reference(the treeing effect)other specifications. If, however, a standard for workmanship can be developed with individual requirements and the requirements, in turn, are complete and do not require other specifications, then the military, or at least Air Force, will publish it. The plans are to develop the standard somewhat like MIL-STD-454, with separate requirements. Unlike MIL-STD-454 the workmanship standards will be totally independent and will not cause other specifications or standards to form a part of the workmanship standard.

The need is clear for creating a unified workmanship document. The task to write a dynamic document that is easy to add to or delete from will indeed be hard.

PRESENTATION - APRIL 30, 1980
MISSION ASSURANCE SYMPOSIUM

Presentor:
D. M. Verrastro -
Manager, Employee/Labor Relations
Martin Marietta Aerospace/Denver Division

Do you feel about your collective bargained agreements like some people feel about their marital status--

(1) I don't like it

(2) I can't change it

but

(3) I can't help dreaming of something better

I hope today to address the viewpoint that the collective bargaining agreement is an instrument that, if not likeable or embraceable, can be at least be tolerated and worked with, can be changed and can by bringing understanding be something better even in its present form today--

"Management has not set high enough quality standards and what they have, are not consistently applied." This is a paraphrase of a recent statement made on national TV news show by a prominent authority in the field of labor relations.

What this person was saying is that it is management's responsibility to set quality standards and apply those standards uniformly. What message could be more clear--

Your Job! Do it!

No way, I can't do it - I'm not permitted to do it - the union contract interferes with my right to do it - and that's the topic of our discussion during the next 30 minutes. I submit to you that the union contract does not interfere with our right to operate efficiently and set high quality standards.

By the way, the prominent authority I've paraphrased is none other than Douglas Fraser, President of the United Auto Workers. Mr. Fraser placed the responsibility or onus on management when asked on the "Good Morning America" show--why do U.S. auto makers have more quality problems than foreign manufacturers with whom they compete.

Mr. Fraser recognizes that we have not only the responsibility to establish quality standards but I suggest to all of you that implicit in his statement is the fact that management has the authority -- Albeit in some cases modified or abridged -- to set quality standards.

Mr. Fraser indeed was suggesting that collective bargaining equates to accommodation of each other's problems.

I. We in management have a problem or we feel that the collective bargaining agreement prevents us from doing our job -- if that's the true case, then we have no right in business today, or we must change our posture (a good example - aluminum - training - transfers)

Collective bargaining equals: accommodation - a dictionary definition of accommodation is: an adjustment of differences.

The union has the right to bargain for its members regarding maintaining and improving working conditions -- that's the union's right -- the union membership expects the bargaining will result in a maintenance and improvement on such items as wages -- benefits. I don't believe that the majority of union members have a desire to put management that is the company out of business in a collective bargaining situation -- although this can and does result -- it is not necessarily an avowed objective of union members and or the institution union to do this.

Management has a right usually expressed in a management prerogatives clause to expect a fair return on its total investment not expressed that way but that's what it says we have a right to manage out business investment. That management usually attains that objective can be readily seen by any review of the fortune 500/1000 companies and their 1979 profitability margins -- which companies, I may add, have employees who are represented by, I'm sure, every union identified as such in this country.

The company has a right to expect that the union representing him will at the very

least continue to support his efforts to maintain his standard of living. They have a right to expect that their employer/the company will at the very least, provide a safe and fair place of employment.

The employee expects that his company and his union can accommodate each other.

II. Collective Bargaining Agreements

Robert's Dictionary of Industrial Relations terms defines a collective bargaining agreement in these words--a contract or mutual understanding between a union and a company setting forth the terms and conditions of employment usually for a specific period of time. The scope and coverage of the agreement will depend on the parties.

The U.S. Supreme Court in the 1961 steelworkers trilogy in a footnote said--

(Gulf warrior)

A collective bargaining agreement is an effort to erect

A system of industrial self *government*.

Nothing in either one of these definitions suggests that collective bargaining is meant to or sets out to destroy the company -- or its products or service.

Most labor agreements in a manufacturing environment, especially in our aerospace environment provide for a quality control organization -- can that mean that Q.C. is b a n n e d/p r o h i b i t e d-- of course not -- just the reverse is true - Q.C. is encouraged to function.

Why doesn't Q.C. function -- in a climate where a C.B.A. exists?

Because -- seniority provisions cause the company to lay-off the junior -- last hired -- but highly qualified employee today -- wasn't that same provision in the labor agreement 10 years ago -- when the man who faced lay-off then was the same man we wanted to protect, but now we say he no longer can do this job -- is that the fault of the labor contract, the C.B.A. or is it our fault for not providing during the last 10 years the training necessary for this once-valued employee -- so that they could function in today's environment -- after all, we got 10 years out of them -- what have we gotten from the new hire?? Are our industry certification programs doing the job? Whose fault is it -- where does the blame lie??

Does Q.C. not function because we must promote incompetence by virtue of the seniority clause?

We in Martin have gathered information from our competitors whenever we prepare for collective bargaining and I don't recall comparing any seniority provision in the aerospace industry that stated -- seniority shall be the only selection criteria in determining promotions. Usually the clause is, and I'll paraphrase -- all things being equal--that is ability to perform the job, then seniority will govern--

If your agreement says seniority is the sole criteria for all promotions, then you do have a problem -- but it is something that can, if you're truly operating at a loss because of this situation -- you can c h a n g e and more and more managements are stepping up to the collective bargaining table and saying, accommodate a very real problem and more and more unions are listening and favorably responding --

Do job descriptions limit quality -- answer: again, is an emphatic <u>no</u> quality is permitted --

The union member wants a job that he can take pride in. Yes, collective bargaining agreement can, and sometimes does, stifle quality performance -- the union is a political entity that tends to the middle of the road -- but the union contract does not snuff out quality -- the union member does not want quality snuffed out -- he/she -- they -- want to continue to be recognized for their achievements; however small that achievement may be; for example, does anybody here have a union contract which would prohibit an employee/union member from going to the customer's location and seeing what the end product looks like -- how it functions -- titan program -- select various in-unit types -- flights to the cape, western test range, etc.

Quality like safety, is an attitude -- create the proper climate, with or without a labor agreement recognize the individual, remove the obstacles and the way we perceive a labor agreement can be a large real obstacle to obtaining performance, clear up our thinking -- correct past practices -- and they can be corrected and we can accommodate quality in the work place, even in a collective bargaining environment.

Let's accept Mr. Fraser's challenge and make collective bargaining work to achieve quality.

IS IT REALLY WORKMANSHIP?

by Paul L. Dalton
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I. INTRODUCTION

Workmanship is defined as the art, skill, or technique of a workman. Poor workmanship is then the lack of these attributes. In speaking of workmanship in the aerospace industry we may ask ourselves, "Are our workmen generally underskilled or undermotivated?" If the answer is, "No", then what is our problem?

To answer this question we need to examine the environment in which we work. While it is true that our work environment is very demanding (probably more so than other industries) and the environment is being changed by trends towards automation and away from hand skills, these are not areas in which our workmanship problems can be addressed. Improvement can only be realized when we understand how defects are produced. The assumption that defects are man related is often not true. Frequently, defects are producted by inadequate or unforgiveable processes and designs. When this is true, defects are highly probable from the beginning concept of hardware.

Significant improvement can only be realized when we understand how defects are being produced and how to eliminate them. Today we will discuss several tools that I think can be effectively applied toward this end.

II. TOOLS FOR DEFECT UNDERSTANDING AND PREVENTION

The tools that we will discuss here are not new but tools that have been around for a long time that need to be dusted off and applied with new dedication and exactness.

A. Design Review

The specific objective of design review is to come up with a design that can be fabricated, tested and flown as problem free as possible. This can be achieved by finding and eliminating problems before they occur. Problems fit into two categories, new problems and old problems. New problems are those introduced into the design by new technologies. Old ones are those that have occurred before on prior programs. The latter normally form a significant portion of the population of problems encountered which serves to stress the importance of utilizing experience, not only your own, but the experience of others who have worked on similar programs.

When assessing a design, it is necessary to allow for variations to norm. The only way to do this is to be very conservative in estimates of capability. Get as much margin in planning, processes, drawings and parts as possible. Margin can be obtained in design by expanding tolerances. Margin can also be obtained by extra care in handling or in fabrication tooling that keeps the hardware relatively stress free.

Problem Examples:

1. Old Problem: Forward and aft OMNI antennas experienced dipole and crossover wire fatigue failures during qualification vibration tests. Yes, I'm aware that qualification tests are to confirm the inherent design capability, but the key word is to "confirm". Prior experience definitely pointed to the need to tie flimsy things like this down. A problem could have been prevented.

2. New Problem: Steerable

Horizon Crossing Indicator experienced bolometer separation from heat sink during acceptance thermal cycling. The coefficient of thermal expansion between two materials (selenium - germanium) was too great, setting up stresses and causing the selenium to crack. The design was not new but the temperature cycles it was subjected to were in excess of what it had ever been subjected to before. Another problem that could have been prevented.

It's true that we always have 20/20 hindsight, but this just points up the need to be technically inquisitive and alert. Obvious problems have a habit of slipping by and are expensive and embarrassing when allowed to become evident as fabrication and test progress.

A point that also must be made is that design review is not just PDR/CDR. Design review is not something that is performed in two days by sitting down with a set of drawings, but involves detail interfaces with designers and others, both inhouse and subcontractors. The review must start as the proposal is being prepared and is really not complete until after launch, although a maximum effort must be focused to eliminate all possible problems from designs prior to release for procurement or fabrication.

B. Process Reviews and Validations

Processes can significantly reduce design margin and detract from the workman's ability to produce an acceptable product. Presented here are a couple of typical process type problems that fit into the old and new categories.

Problem Examples:

1. Old Problem: High thrust engine thrust chamber valve failed pull-in and drop-out current tests. Water flush induced abnormal drag between polished steel surface on plunger and polished steel surface on valve wall. Alcohol flush eliminated problem. This was another case of falling back into a known trap.

2. New Problem: Initial wave soldering of PWB's with Macdermid Macu-Mask solder resist with traces equal to or greater than 0.050 resulted in cracking of resist and subsequent entrapment of liquid contaminant. The process had been validated on boards with narrower traces without a problem.

It can be seen that the afore listed problems should have been prevented. The examples, and many others any of us could think of, stress the need to carefully evaluate each step of the process. A technique of process evaluation might consist of a series of questions such as the following.

1. What effects will it have on the materials being applied?

2. Does it involve only operations within normal workman skills, or are there difficult operations that require special training?

3. Are there any new or state-of-the-art applications or operations?

4. Are inspections/tests clearly defined and are they completely adequate to assure that the article in all respects meets the design requirement?

5. What prior problems are known to exist with this type process?

6. Have all the pitfalls been recognized and eliminated?

Once the review effort is complete, the next step is process validation. This involves gathering the Process Engineer, Quality Engineer, and manufacturing/fabrication personnel together in the actual work environment (location and hardware) to confirm that each step that is written on the paper is clearly understandable and implementable in the fabrication environment.

C. Software Reviews/Validation

For the purpose of this paper, I don't want to write a treatise on software (it's a subject all by itself), but I do want to point to the need to exercise the same type tools, the same type vigilance and control on software that we do on hardware. Software errors are time consuming and expensive, and most that we experience are preventable.

The problems, as in hardware, can start anywhere in the development process. Post analysis of software problems has indicated that, most frequently, they are traceable to the following basic development process weaknesses.

1. Lack of requirements definition.

2. Inadequate designs from which to code.

3. Complex coding techniques making it difficult to see errors.

4. Lack of adequate documentation to trace actions and lack of modularity and maintainability.

To be effective, Quality must focus its effort on each phase of software development, coding, testing, configuration control and, last but not least, failure analysis and corrective action. An effective failure analysis and corrective action effort that inists that the cause of each problem is determined and assure that corrective action is assigned is equally as important in software as it is in hardware.

D. Training

Most of us in the industry have training programs because we know that they are necessary to assure that worker skills are maintained at an acceptable level. However, I believe that at times there may be a tendency to allow the training programs to kind of take their own course and, thereby, tend to lose their relevancy. To be effective, training must be specifically directed towards the work that is to be performed. This involves verifying performance capability of workers on actual hardware and under typical shop work conditions. This means that you have to stay on top of your training program all the time to be able to recognize when needs are changing. It is also very important to continuously monitor work results to identify specific workmanship problems and training inadequacies.

Another very valuable tool that can be utilized to find problems leading to workmanship deficiencies is to talk to the workmen. The people that do the work day in and day out know where they are encountering difficulties and if they tell you that your process or design stinks, you better believe them. The problems discovered must then be worked in some way. If it's not feasible to change the design or process, certainly the manufacturing techniques or training needs require investigation.

E. Failure Analysis and Corrective Action

The first thing I would like to mention here is attitude. The attitude that says a certain number of failures is inevitable. Yes, I know what happens in the real world. But to start with an attitude that some failures are inevitable means that I start not shooting for 100%. I believe that this tends to lull everybody into a ho-hum approach to problem prevention. We need to expect success and have a real conviction going in that all the holes are closed.

Then, if a failure should occur, you leap right on top of it to find the hole that was not closed. Each failure or problem must be investigated to isolate the root cause and corrective action taken to prevent recurrence. Many times I have become involved with problems where it was stated that nobody had any idea what to do for corrective action. Almost without exception, it was discovered that the real problem was that the cause of the problem had not been defined. Corrective action becomes very evident when it is understood what (cause) must be prevented.

To provide a typical model for evaluation, I have taken significant problems from a typical spacecraft program and categorized them by causes into design, process and workmanship. It is recognized that the evaluation of what fell into which category was somewhat arbitrary, but the figures should be representative. The relative percentages for the significant problems were 54% design, 20% process, and 26% workmanship.

This was a one of a kind type program that went directly into production as opposed to one where there was significant development effort. This may tend to explain the relatively higher number of design problems. Also, another contributing factor is that only significant problems were selected. These were the problems that commanded significant attention either from a technical, schedule, or cost impact. Regardless of whether the ratios seem quite right, it clearly points to the need to focus attention on all areas - all were significant contributors. The sample taken and the examples given also included many problems that occurred at subcontractors, so it clearly indicates that the actions taken must not only be focused on in-house activities, but on subcontractors as well.

III. Specification Problems

I don't have a tremendous axe to grind in this area, but some problems did occur to me that we have encountered before.

The first problem is with MIL-S-45743 which limits flux usage to RMA only. This is fine for most solder applications, but there are cases, certain lead materials, etc., that would react better to more active fluxes.

Another case that comes to mind is MIL-C-46058 which requires conformal coating other than the conformal coat we normally use. This could contribute to a workmanship problem if we were forced to change due to the new process. So far, we have been able to get an exception for every program that allows us to use our normal conformal coat.

The more common problem that I have run into in this area is excessive interpretation of well meaning specs. A typical example here is with MIL-S-52779 which requires control of nondeliverable, as well as deliverable software. The requirement is wide open for interpretation and if interpreted literally, will involve a lot of effort and expense that will not have any positive

impact on product quality.

The problems then fall into two categories. In the first case, if the problems are not noted and worked, you have a negative impact on product quality, and in the second case, you have energies and attentions diverted from significant to insignificant tasks.

IV. Conclusion

One conclusion that we can definitely draw is that it's not going to be effective to address workmanship as a general problem. It's a many faceted problem that must be addressed specifically towards a known problem area to realize improvement.

I think that motivational programs are beneficial, especially those that let workers know that they are an important part of the team, but it's not a panacea. As a matter of fact, motivational efforts directed towards workmanship improvement without a determined effort in evidence to eliminate defects can be negative. All we do is convince the workmen that we don't know what's going on.

A number of tools have been discussed here today, and it's my conviction and experience that they can be effectively applied. I believe that tools of this nature, rigorously and exactly applied, are not only needed but are necessary to perform in the aerospace work environment.

MANUFACTURING READINESS FOR PRODUCTION

Richard A. Sipe

IUS MANUFACTURING MANAGER
BOEING AEROSPACE CO.

Manufacturing readiness for production starts early in the design phase of a program with integration of design and production producibility analysis activities. Increased emphasis is being placed by the Government on production management early involvement in the product acquisition cycle. Special attention is being demanded to decrease production costs prior to as well as during production. To meet this objective planned, explicit, and timely assessments of the production management implications and production risks are necessary from the beginning of the acquisition cycle through the decision to go into production.

Mil-Std-1528, "Production Management," describes the Air Force requirements for an effective production management system. This Mil-Std was written to be applied in total, or tailored to, the specific requirements of each contract based on program technical complexity, production risk, production cost, scope of production operations, and potential for program impact due to production operations. Implementation of Mil-Std-1528 typically requires documentation (a formal production plan) and the conduct of formal production readiness reviews prior to transition from full scale development to production. The following discussion is drawn from my Boeing manufacturing operations experience with several programs, but particularly from IUS.

The success of a product such as IUS is established during the design phase of a program. For example, during the IUS concept (validation) phase, Boeing designed the upper stage vehicle, developed and tested certain high risk hardware, and conducted many major tradeoff producibility analyses. Manufacturing's key role during this early phase involved fabrication and assembly of developmental test hardware, initiation of a producibility program for design analysis and supportive trade studies on alternate design concepts, participation in subcontractor source selection surveys, preparation of preliminary make/buy plans, and preparation of a preliminary production plan.

Certainly a key activity to the development of a good production plan is the determination and optimization of the product's producibility. Producibility considerations during preliminary planning include economic evaluation of alternative configurations, materials, methods, processes, technology, tooling, test equipment and procedures, sequence of processes, factory layout and flow, lot size, cyclic demand, packaging and handling, inspection, manual versus computer part processing, and capability and capacity versus outside source development. These considerations also include review of drawings, specifications, test procedures, and tool and production planning to verify that all necessary information is included for the craftsmen in the factory to fabricate, assemble, install, and test parts and assemblies within program requirements. This activity requires a coordinated effort between the designer and manufacturing engineer responsible for a hardware package. Theirs is a continuing relationship from concept through final determination of a production configuration. They are supported, as necessary, by Materiel, Manufacturing Technology, Industrial Engineering, Quality Assurance, and Factory organizations to assure that all elements affecting a cost effective, reliable end product are identified and incorporated.

While producibility analysis is a significant activity in reducing production risk, it is not always a precise science. It is more of an art, where perseverance and just plain hardnosed experience are the key to success. To explain what I mean, let me relate the PDU chassis story. The power distribution unit (PDU), one of the IUS electrical power distribution system electronic boxes, was design-specified as a welded chassis assembly constructed of many 6061 aluminum detail parts. Producibility analysis of the PDU chassis resulted in the following:

- o Reduction in part count by 32 (44-12)
- o Reduction in manufacturing flow time by 48 mandays (90-48)
- o Reduction in linear inches of weld by 375 inches (many multiple passes)
- o Weld repair drastically reduced through use of 2219 aluminum material
- o Heat treat eliminated (age only)
- o Weld engineer surveillance virtually eliminated
- o Factory labor manhours per unit were significantly reduced

o Product quality and appearance greatly enhanced

This story makes the point that craftsmanship in the factory must be backed up with craftsmanship in design, producibility analysis, and production planning to achieve optimum end product results.

Not all hardware in any system is made by the prime contractor, so attention must be paid to the subcontractors and their producibility analyses and documentation. Engineering, Manufacturing, and Quality Assurance provide technical support to the subcontractors in their producibility evaluations.

As noted earlier, one of the Government initiatives promulgated through Mil-Std-1528 is the requirement for formal production plans. Documentation portrays "Methods and concepts for employing facilities, tooling, and manpower resources of the contractor and subcontractors. It reflects all time-phased production actions required to produce, test, inspect, and deliver acceptable contractual end items on schedule at minimum cost."

The production plan usually is comprised of the following sections:

I Manufacturing Organization
II Make or Buy
III Subcontracting
IV Resources and Manufacturing Capability
V Production Planning

Detail requirements for each section of the production plan can be found in Government Data Item Description DI-P-3460. The significance of the production plan is that it provides a detailed "road map" from drawing to completed hardware. It incorporates the results of producibility analysis and trade studies. It is submitted to, and approved by, the Government and updated during various program phases. Properly done, a production plan is Manufacturing Man's bible.

Using the production plan as a baseline, verify that your homework has been done and your planning is complete. This requires the contractor and the Government to conduct indepth reviews. As an example, I will describe how Boeing and Space Division/NASA conducted reviews of IUS readiness for production.

DOD Instruction 5000.28 describes the objective of a production readiness review (PRR) as follows:

"To verify that production design, planning, and associated preparations for a system have progressed to the point where a production commitment can be made without incurring unacceptable risks of breaching thresholds of schedule, performance, cost, or other established criteria."

The criteria for conduct of PRRs are provided in AFSCP84-2 and overall production management evaluation approach is documented in AFSCP84-3. These instructions deal with functions that are highly specialized and subject to differing interpretations, definitions, and understandings. Many program/functional groups in Government/contractor organizations are impacted. Misunderstanding of interpretations and requirements can be avoided by very early joint participation by contractor and the Government in developing a production readiness review plan.

The Boeing/Government team who conducted 11 PRRs at subcontractors supplying mission critical hardware to IUS were, for the most part, the same team that conducted the Boeing PRR. During the subcontract PRRs, Boeing conducted the review with Government team members acting as advisors. During the Boeing PRR, the roles were reversed with Government team members conducting the review and Boeing team members providing the information. This is an effective way of developing an integrated industry/Government <u>team</u> early in the program. It provides a mutual understanding of system elements, functions, and interfaces and leads to an efficient and economical system-level review.

I believe I can offer a few "Lessons Learned" which may help in demonstrating manufacturing readiness for production.

<u>Do</u>:

- o Understand what PRRs are all about and the significance the customer places on them.
- o Posture yourself early enough to be ready.
- o Review and prepare
  - o Agenda
  - o PRR criteria and ground rules
  - o Program's themes/messages
  - o A single thread story
  - o Understand all other elements, functions, and interfaces
- o Reflect a single program team approach.
- o Use the production plan as baseline for the PRR.
- o Be responsive to the customer and understand his requirements at all times.

- o Prompt a response-oriented session where the customer will discuss his concerns.
- o Balance showmanship with substance.

Don't:

- o Surprise the customer in a PRR.
- o Forget to be prepared to address problems encountered during developmental phases and do show how they were solved before production.
- o Indicate everything is peaches and cream; risks do exist; therefore,
  - o Identify risks
  - o Show good abatement plans, and
  - o Show that risks are controlled.
- o Forget to follow up on questions, comments, or last PRR issues.
- o Be caught on Mil-Stds (1695, 1520A, 1567, 1528, etc.).
- o Develop a proposal one way and really plan to do it differently.
- o Try to con the customer; they are as smart as you are and have probably been through this more than you.
- o Hipshoot answers - get back with specific details.
- o Give impromptu demonstrations; if a demonstration is worth giving, it is worth preparing for.

In summary, three recommendations are offered:

- o The Contractor/Government must mutually define the manufacturing readiness criteria early in the program.
- o Utilize resident Government agencies (AFPRO, DCAS, NASA) in the planning and conduct of production readiness reviews at both the prime contractor plant and subcontractor plants.
- o Contractor/Government must both do your homework; know the production plan, and the design and specification requirements before reviews are conducted.

CRAFTSMANSHIP MANUFACTURING READINESS

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Increased emphasis is being placed by the government on production management early in the acquisition cycle; More attention is being paid by the government to specific programs to decrease production costs prior to and during production. Summary of the discussion is as follows:

A. Engineering/Product Design

Engineering and product design are reviewed and evaluated to assure that:

1) Producibility analysis and production capability were accomplished.
2) Cost effectiveness studies were accomplished.
3) Risk analysis accomplished and new production methods or techniques determined.
4) Contractor made maximum use of military standard components, parts, and processes in the design.

B. Manufacturing Planning

Rescue production capabilities are determined which can be used to minimize unforeseeable delays or expansion of schedules. Production organization is reviewed to determine if schedule adjustments can be accommodated. Industrial engineering responsibilities and authority for in-plant layout and flow processes is evaluated. Actual observation of manufacturing and assembly operations is accomplished to assure efficient and effective:

1) Machine scheduling and loading
2) Machine and tooling setup
3) Manpower utilization
4) Minimum scrap or rework items
5) Adequate work instructions for the workers

Utilization of latest manufacturing methods and techniques are determined along with evaluating the adequacy of contingency manufacturing plans.

C. Production/Manufacturing Operations

Production and manufacturing operations are reviewed and evaluated for the following items:

1) Evaluate contractors program for assuming adequacy of production skills.
2) Determine extent that production management is responsive to new and advanced production management techniques and advanced production processes and techniques.
3) Review clean room facilities.
4) Determine if automated production procedures provide adequate information regarding the status and location of work-in-process, allocation versus actual time, and other useful information.
5) Determine if manufacturing has a systematic program for calibration of production process gauges.

D. Production/Manufacturing Methods and Processes

Specified methods or processes are evaluated to determine if trial runs prior to initiation of production has been accomplished. Efficiency standards must be maintained for each machine, department, or process. Actions taken to provide for differences in tooling, material, and process control and operator effectiveness in transitioning from full-scale development to production is reviewed. The methods and procedures to be used to identify discrepancies between scheduled and actual production are reviewed.

E. Tooling and Test Equipment

The quantity, type and cost of special tooling and test equipment used for assembly, fabrication and test is evaluated. Also

the planned use of numerical control machines for effectiveness of operations is reviewed and evaluated. The prime contractors' evaluation of his major subcontractor's tooling plans, concept, and capabilities are reviewed. Ensure that tooling procedures and contingency plans have been prepared and are adequate to assure uninterrupted and continued production.

F. Facilities and Equipment

Determination if more modern equipment is justified to reduce machining costs, provide less downtime, and lower maintenance costs. Planned requirements and use of numerical and tape controlled and other high cost automated equipment is reviewed. Also the planned equipment is reviewed to determine producibility of acceptability of parts to support the production rate.

G. Subcontracts

The contractor's subcontract structure is reviewed to determine if a periodical reexamination is accomplished to assure that existing subcontractors remain most economical and advantangeous to the program. Controls employed by subcontract administration for monitoring and forecasting unsatisfactory conditions relating to scheduled deliveries are evaluated.

H. Quality Assurance

Design review process is evaluated to determine if Quality Assurance has participated by assessing the adequacy of existing equipment and procedures to control product quality. Procedures for control of special processes and systems are reviewed for adequacy and the quality controls established for materials treatment and processes to be used in production are evaluated.

I. Manpower

Labor quantities and skills required for production are reviewed and determined if adequate. Worker efficiency factors, certification of workers in critical manufacturing processes, adequacy of skills and employee development plan to improve capabilities, productivity and efficiency are all reviewed.

CONTROL OF CRITICAL ITEMS

John Q. A. Wickham

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SUMMARY

Critical items are weapon or space system hardware assemblies that must operate without loss of function in their end usage, else the system experiences catastrophic failure.

Critical items and their control are discussed in terms of their Government specification requirements and selection. Experienced control elements and techniques are detailed. Issues arising out of experience in initiating and accomplishing a critical items program are discussed.

- Should most time and money for a critical items program be concentrated on subcontractor items?
- Is the cost of control significantly less than potential program losses with significant probabilities?
- How is the stumbling block of "proprietary processes" best negotiated?

SPECIFICATIONS

Government specification of requirements and control of critical items is documented in NHB 5300.4 (1D-2), "Safety, Reliability, Maintainability and Quality Provisions for the Space Shuttle Program," and MIL-STD-1535A, "Supplier Quality Assurance Program Requirements, MIL-STD-1543, Reliability Program Requirements for Space and Missile Systems."

SELECTION

The specifications call for selection of critical items by accomplishment of failure modes and effects analyses (FMEAs), which define mission critical failure modes. Figure 1 illustrates an FMEA example. The specifications call for special attention to the specification, manufacturing operations, inspections, and test planning relating to selected critical items. Selection of critical items is tempered by considerations of complexity and program peculiar requirements, such as customer desired experience data. Critical items tend to be hardware assemblies that are field replaceable.

MIL-STD-1535A, being a supplier control document, considers subcontractor supplied critical items (registered components). The program principal contractor might tend towards selection of subcontractor supplied items since he knows less about them compared to his own hardware. The customer normally has more insight into the contractor hardware than supplied items. Subcontractor proprietary processes/configurations can be a principle stumbling block to establishing a critical item program. Clear communication between the subcontractor/contractor is all important to minimize this potential problem.

CONTROL ELEMENTS AND TECHNIQUES

A critical item control plan is documented which lists the critical items along with their data requirements and required processing/inspection methods. These requirements and methods are reviewed and approved by the contractor.

The plan normally becomes a part of the program quality assurance plan, see Figure 2. It also may be converted to a data requirement for subcontractor response.

Critical items and their requirements should also be documented in released engineering to assure change control and provide authority for imposition of the requirements in factory planning and procurement.

Aerospace and military programs concerned with relatively few, highly expensive, high reliability systems should consider the pedigreed critical item as a method of control. Such a critical item carries its total, detailed success/failure history with it through fabrication and test until end use. Its history is evaluated (flight certified) by a design/reliability engineering team at predetermined milestones to determine end use acceptability. This evaluation is over and above normal inspection and is accomplished to detect adverse, in-tolerance performance trends as

well as possible operating overstresses and unresolved functional failures. Figure 3 is a flow diagram depicting the generation and compilation of the failure/success data as well as the subsequent evaluation (flight certification) by the engineering team.

The requirements for pedigreed critical items are documented in a released engineering document. These requirements are then called out in the factory planning traveler which accompanies the item through production and test. Inspection initiates and maintains a compilation of build, test and rejection history (history jacket) in compliance with the planning callouts. This history jacket is reviewed by the Design/Reliability Engineering Team (Flight Certification Board) upon completion of acceptance testing. Upon flight certification by the Flight Certification Board (FCB) and installation of the critical item into its end system, the history jacket is supplanted by a log (System Event Log) chronologically listing system events at vehicle level. The System Event Log with supporting test data is flight certified at the vehicle launch site prior to flight.

ISSUES ARISING FROM CONTROL OF CRITICAL ITEMS

A critical item control activity adds significant cost to the overall program. It is important to compare that cost to the risks to the overall program without critical items control.

It appears that it might be program beneficial to concentrate critical item control activity on subcontractor items rather than contractor items since less information is available for the former items.

Classification of processes by the subcontractor as "proprietary" represents a potential stumbling block that requires clear and definitive communications between the subcontractor and contractor.

It is vital that critical item control plans be tailored for each item. Boilerplate plans tend to exaggerate the size and cost of the task in the eyes of the subcontractor.

GENERAL DYNAMICS
Convair Division

CRUISE MISSILE - FAILURE MODES & EFFECTS ANALYSIS (FMEA)

Page 8

SUBSYSTEM: PNEUMATIC POWER/MECHANISMS
COMPONENT: EXPLOSIVE VALVE, WING DEPLOY
PART NO.: 7EZ3130-4
REF DWG/SCHEMATIC: 7EZ4480-4
REF. DESIG./REF NO.: EV-2

COMPONENT FUNCTION: ELECTRICALLY INITIATED THREE-WAY EXPLOSIVE VALVE THAT CONTROLS PRESSURE TO ACTUATOR THAT EXTENDS WINGS.

PREPARED BY R. YOCOM DATE 01/04/80
REVIEWED BY DATE

MISSION PHASE OPERATION
A) Prelaunch C)
B) Boost Flight D)

ENTRY NO.	FAILURE MODE	FAILURE CAUSE	FAILURE EFFECT ON: SUBSYSTEM	FAILURE EFFECT ON: MISSION	CRITICALITY: MISSION	CRITICALITY: SAFETY	FAILURE DETECTION METHOD	MAINTENANCE ACTION REQUIRED	PREVENTION AND/OR CONTROL SAFEGUARDS
6	Fails to actuate	a) Initiator failure b) Electrical connector failure. c) Ram frozen in valve body d) Shear tube wall too thick	Pressure cannot be vented from head end of actuator to allow deployment of wings.	B - Loss of mission	X		None	None	Initiators fully qualified per MIL-I-23659, Rev. C. Lot sampling acceptance tests of valve assemblies. 100% radiographic inspection of valves Continuity check during final system checkout.
7	Leakage/Rupture	a) Valve body failure. b) B-nut failure c) Ram binding	Fuel tank bladder requires vented pressure for fuel to the engine on engine start.	B - Possible loss of mission - Reduction of pressure to fuel tank bladder.	X		None	None	Lot sampling acceptance tests of valves. Proof pressure testing of all valves. Post-installation leak tests at section and system levels of vehicle assembly.

Figure 1. Example of failure modes and effects analysis.

SUBJECT: CENTAUR D-1 CRITICAL ITEMS LIST (COMPONENTS)			Prime Specification Chapter/Section/Paragraph No.	
			NHB 5300.4 (1A)	201.d
			NHB 5300.4 (1B)	
Issue 4	Date 1 December 1975	Page 1 of 6	SAMSO-LVV-002	

APPENDIX A-1
CENTAUR D-1 CRITICAL ITEMS LIST (COMPONENTS)

4 The items listed below as requiring history jackets and/or data submittal are correct as of 1 December 1975. This requirement is constantly changing and will be kept current only in Convair publication 55-00091 (AC-CCR). 4

*FLIGHT LEVEL ACCEPTANCE TEST		USAGE					LAT DETAILS ONLY								FACTORY			SITE				
		D-1A	D-1T	*FLAT	HISTORY JACKET	DATA SUBMITTAL	QUALIF. REQD.	PARA. DOCUMENTS	FUNCTION	TEMPERATURE	VIBRATION	ALTITUDE	LAT	OPN. LIFE CONTROL	SUBSYSTEM	SYSTEM C/O	INTEGRATED	SYSTEM	TANKING	FACT	CRT/TCD	COUNTDOWN
SYSTEM 023, ATLAS/CENTAUR SEPARATION																						
55-74355	Detonation transfer assembly	x	x	x	x		x		x	x		x	x	No								
55-74365	Dual detonator assembly	x	x	x	x		x		x	x		x	x	x								
55-75882	Shaped charge assembly	x	x	x	x		x		x	x		x	x	No								
SYSTEM 025, INSULATION PANELS AND SEPARATION																						
55-74352	Shaped charge assembly	x		x	x		x		x	x		x	x									
55-74355	Detonation transfer assembly	x		x	x		x		x	x		x	x									
55-74362	Shaped charge assembly	x		x	x		x		x	x		x	x									
55-74365	Dual detonator assembly	x		x	x		x		x	x		x	x									
SYSTEM 027, NOSE FAIRING AND SEPARATION																						
27-76275	Jettison sys. actuator assy. (fwd)	x			x		x		x					No				x				
55-06018	Explosive cartridge	x	x		x		x						x	x								
55-07057	Explosive-actuated bolt	x	x		x		x						x	x								
55-07103	Explosive cartridge	x			x		x						x	x								
55-08019	Explosive cartridge	x			x		x			x	x		x	x								
55-74355	Detonation transfer assembly	x		x	x				x	x		x	x	n								
55-74365	Dual detonator assembly	x		x	x				x	x		x	x	x								
55-74382	Shaped charge assembly	x		x	x				x	x		x	x	No								

Figure 2. Example of a Critical Item Control Plan as Part of a Quality Assurance Plan

CONTROL OF CRITICAL ITEMS

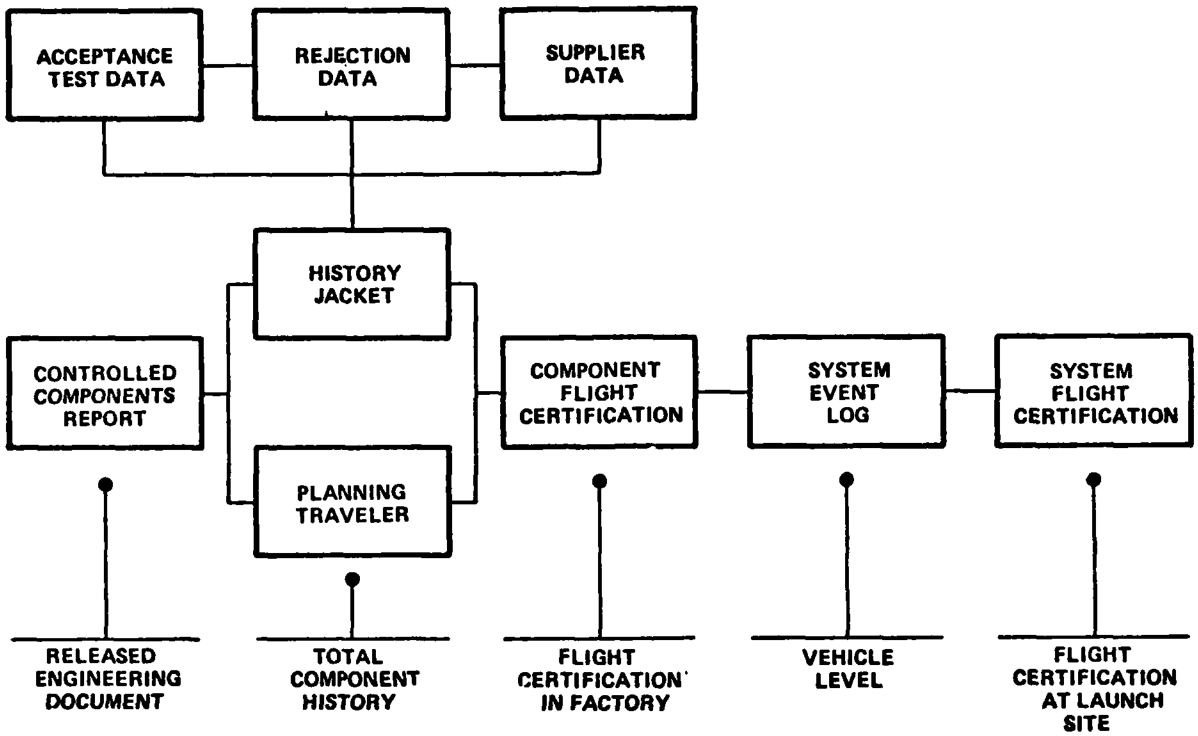


Figure 3. Controlled components - major events.

A NEW DIMENSION FOR QUALITY

B. J. (Bill) Chumbley

BELL HELICOPTER TEXTRON

CAD/CAM is currently being promoted as the most effective way of providing the ultimate in efficient, yet error-free design, manufacturing and control disciplines. By the elimination of the human element, computer controlled machines will assure that the same function will be performed the same way every time. In theory, this appears to be the Utopia that we have been searching for. In practice, however, it has become very clear that, for the system to work effectively, periodic measurements and adjustments must be made.

A computer cannot act. It can only react to programmed stimuli. Human beings must program the computer before it can react. Humans are subject to human error. Thus, the ability of a computer controlled activity to function accurately depends upon the accuracy of the programmer. When the additional factors of machine repeatability, tool wear and proper placement of tools and fixtures are introduced, the probability of an error-free operation begins to diminish. Left uncontrolled, the process can rapidly deteriorate into a state of unprofitability.

Although the traditional methods employed to design and produce a product have been altered by the use of the computer, the basic goal of providing the customer with a product that meets his expectations remains intact. The areas of quality assurance, however, must now be shifted upstream into the manufacturing cycle and ultimately into the design phase if the CAD/CAM system is to be economically controlled. This then requires additional emphasis being placed on the software portion of the package and modified programs of process control in lieu of only inspecting the finished part.

Because of the relative "newness" of CAD/CAM, program definitions used to control this concept remain rather obscure and vary from one company to another. Basically, this problem of uniform control principles can be cited in three "lacks":

1. The lack of understanding of how it works.

2. The lack of a set of commonly accepted controls.

3. The lack of a uniform documentation requirement.

In this paper, we will examine what CAD/CAM consists of so that the other two areas can be better addressed. In the first part, we will provide answers. In the other part we will provide only facts upon which decisions must be made in order to provide an effective means of control.

To begin, let's define what CAD/CAM actually is. CAD/CAM is the acronym that has been coined by our computer people to describe a philosophy of creating a totally computerized automated system for designing and producing a product. It is not an art. Neither is it an exact science. The CAD portion stands for Computer Aided Design. The CAM portion stands for Computer Aided Manufacturing. The slash between the CAD and the CAM is placed there to indicate an "either or" situation. Either one of the systems can be used separately or in conjunction with one another.

The CAD, or Computer Aided Design, deals with the design portion of the system and involves the use of computer graphics to assist in the calculations and physically defining the part to be designed and programmed. In the place of the traditional drafting table, calculator, slide rule, reams of paper

and numerous volumes of reference data, the designer is equipped with a console (see fig. 1). The tools of his trade consists of a picture tube (or CRT), a typewriter keyboard, a function selector box and a light pen. When the screen is turned on, there will appear a series of function listings above and below the borders shown on the CRT. The designer may select any of the programmed functions by merely touching the screen at the position he wishes the function to appear, and then punching the proper button on the function selector box. An image of this maneuver will appear on the screen. The designer continues to repeat these maneuvers until the design is complete. He then punches another button and the program is transmitted to the computer for storage. If hard copies of the design are needed, provisions can be made to have the computer print either an aperture card or paper print.

Manufacturing planning activities also enjoy the benefits of increased accuracy and time savings by the use of the CAD system. The planner may call the design up on the screen and progressively plan the manufacturing steps in reverse order of fabrication. (Thus, he starts with a finished part and plans back to the starting material configuration.) As the machine sequences are being formulated, NC tapes (or programs), holding fixtures and cutter configurations can also be designed and ordered. When the planner is finished, his input is also stored within the computer.

Now, let's explore the CAM portion of CAD/CAM. This is short for Computer Aided Manufacturing and principally applies to the control of metal cutting machines.

A typical basic machine tool is equipped for three directions of movement, as illustrated in fig. 2. The work platform can be moved from side to side or in and out. The head, or cutting tool holder, is equipped with up and down movement capabilities. On some models the up and down movement is provided by moving the work platform up or down, while the cutting tool holder remains stationary. If we label these three axes of travel x, y and z, and assign numerical values along each axis, we can then pinpoint the exact location and depth of the cutting tool upon an imaginary grid on the machine.

If we choose to attach a servo motor to each of the lead screws that propel the work platform along the x and y axes and the head along the z axis, we can write a program that directs the machine to relocate to a specific position by specifying the x, y, and z location in a numerical equation. Thus, the term "numerical control" (or NC) was coined to denote this family of machines.

There have been four generations of NC machines developed within the past 30 years. These are known as NC, DNC, CNC, and DPNC.

NC, simply called Numerical Control, consists of a machine tool capable of receiving its instructions from an integrated controller on the machine. The controller reads the program from a punched tape, processes the language into electrical impulses which, in turn, operates the machine. This family of machines is commonly referred to as "tape" machines.

The first attempts at a direct hookup between a machine tool and a computer produced a generation of machine tools known as DNC. DNC consists of a computer in which a machine program has been stored; a controller that is capable of receiving the program from the computer and translating it into machine commands; and machines equipped to receive the commands from a controller. In this set-up, one, two, or any multiple of machine tools may be

hooked into this system and operated by a single controller. Two drawbacks exist with this system, however. First, all machines can produce only one part configuration, and, if the computer or controller breaks down, the whole system goes down. The major advantage of a DNC system is the central control of a battery of machines with one piece of program media.

As the computer technology advanced, computers became smaller and less espensive. Be equipping a microprocessor with a memory and input/output circuitry, a microcomputer small enough to be included on an NC is obtained. Presently, this system of control is the most predominant within the industry. Known as CNC, the machine receives its coordinate commands from a program stored in its integral computer. Permanent storage of the machine programs is provided in a main, or parent, computer and are fed to the machine upon demand.

The fourth generation of NC machine tools are beginning to make an appearance on the scene. Machine tools within this category are equipped with the capabilities of both receiving and transmitting programs to the storage (or host) computer. In addition to reacting to program directions as a CNC does, programs can be modified on the machine and the modified program transmitted back to the host computer. Additional attachments may be added to this machine tool that will allow punched tapes or computer programs to be made while a part is being machined. Upon completion, these programs may be transmitted to the host computer for permanent storage. Because of the two-way communication channel, this machine tool concept is known as Distributive Process Numerical Control, or DPNC.

From the above discussion, it would appear that computer technology has provided almost all of the answers for an efficient manufacturing system. One factor, however, remains unresolved. This is the question of economical, yet efficient product assurance at the customer level. Consumer demands for product safety and reliability considerations have been augmented by government regulations and consumer advocate activities. This results in added pressure on the producer (and especially his Quality Department) to take every reasonable precaution of assuring that only good units of product are offered for sale.

Inspection (i.e., physical measurement of a finished part) is the traditional method of assuring that the parts passed on are within the limits of the design specifications. Before the introduction of NC, one inspector could normally inspect the work of eight machinists with a reasonable degree of accuracy. Today, one NC machine can perform the work of five to twelve conventional machines, while holding intricate dimensional relationships and tolerance never before attainable. Parts can be produced in a few hours that will require several hundred hours to measure when traditional layout methods are used. Of paramount importance, however, is the fact that inspection only sorts the good from the bad. It does not prevent the defect from occurring.

Quality Control, in its ultimate form, assures that the product meets all previously established requirements and that the process is controlled within specified limits. Again, however, the effectiveness of a quality control system depends upon its ability to measure the product in a timely manner.

American Machinist Magazine describes the science of Quality Assurance as a predictive process. "To be effective, it requires assessment, monitoring, and control.

Every process in the manufacturing cycle of a product must first be assessed to determine its potential for meeting previously established quality requirements. Once the process is selected, it must be monitored to make sure that the assessment of its potential is still correct. Finally, the process must be controlled on the basis of such monitoring to keep the process under control" Under the terms of this treatise, every process in the manufacturing cycle must be assessed. This means that Quality must gain the expertise in the computer technology-related manufacturing practices, as well as conventional machining modes, in order to properly assess the manufacturing process currently in effect in the present hybrid machine mix employed by most shops. As more and more computer technology is introduced, this requirement for computer-oriented Quality Engineers will become increasingly acute.

In the last decade, the emphasis of computer technology has been applied to producing the part. Little effort has been made across the industry to provide equipment that will economically measure the product during selected stages of manufacture. As a result, each company has attempted to design their own inspection screens. This has often been accomplished by selective sampling, composite gaging, and reliance on the NC machine to produce a good part. Partially because of the lack of computer technology expertise and principally due to the lack of adequate funding, the Quality discipline has lagged behind the accelerated advancement of its production counterpart.

Quality Assurance, as a discipline, must re-examine its position of Product Assurance, especially in the area of machined parts. In high volume, continuous production environments, the use of sample inspections and control chart concepts have proven to be adequate for controlling the quality of the end product. Process controls have been demonstrated to be successful in the control of heat treatment and chemical process operations. First part inspections, combined with sampling of the finished lot is also a popular means of control. Although these methods have been proven to be successful in the past, their effectiveness in controlling the machining concepts of tomorrow will, at best, be marginal. Consider for a moment these facts:

- Lot sizes are now less than 50 pieces for 75% of all production runs.
- 90% of all NC machine programs take less than 27 minutes to run. 48% are run in less than 10 minutes.
- Rework of part nonconformities are almost non-existent on most NC machines.

Once these facts are examined, in the light of today's Product Assurance programs, it is immediately apparent that additional expertise and measurement capabilities must be obtained. Otherwise, prohibitive scrap and rework costs and excessive inspection bottlenecks will impede the progress of improved machining productivity. The other alternative of relying on the machine's ability to produce only good parts could prove disasterous in light of today's product liability litigations.

A successful quality assurance program for the CAD/CAM concept must begin at the earliest stage of the program--the design phase. Decisions must be made to how and where the product will be measured for compliance. Inaccessible dimensional relationships and specification contraditions should be resolved before the manufacturing effort is initiated. Additional

measurement equipment and programs that will be required to verify the product can be ordered in advance to assure its availability, when needed. In many companies, modified forms of this program are currently in effect. Most of the evaluations, however, are currently made from a formal blueprint, after the design has been finalized.

In the CAD/CAM era, two new factors must be considered. The blueprint will be a video portrayal on a scope and the machining will be performed in a fraction of the conventional machining time on a computer controlled machine. In order to perform an adequate assessment of the design and develop an effective, yet economical verification program, the Quality man must have sufficient expertise in both computer technology and shop practices.

Since operator compensation cannot be made for such variables as worn lead screws, slack bearings and cutter wear on a NC machine, maintenance and calibration controls are of paramount importance. From experience, we have proven that the desired metallurgical properties can be obtained during heat treatments if we adequately control the furnace and sample the lot of material. These same results can reasonably be expected from an NC machine if adequate evaluations are scheduled in a timely manner. Several factors must be considered in designing such a program. Among the more prevalent areas are the following:

- Machine Installation: The initial machine installation, leveling and adjustments made should be verified. The use of a laser interferometer for verification of the installation can provide the required degree of accuracy at a reasonable cost.

- Periodic Calibration: Periodic calibration checks on a machine will assure that the machine is still capable of maintaining the tolerance allowables of a design. The use of test programs to make a test part with given dimensions approximating all of the machine moves have been used quite successfully. Position checks measured by laser interferometer have also proven adequate.

- Tooling and Cutter Control: Quality verification of tool holder settings, tool regrind and holding fixtures will provide an additional degree of assurance. Cutter wear studies provide for changing the cutting tool before a nonconformity appears.

Automated inspection equipment is beginning to appear on the market. Computerized coordinate measuring systems are now available that can provide a wealth of analyzed data. Non-contact gaging concepts are being pursued by many companies, among the more notable being United Technologies Research Center (laser diodes), EMI Photo-Electric (Comp Gage System), and Jones and Lamson (Metric Eye). Total system quality control is the goal of Lockheed Missile & Space Company's IPQC System. The ultimate selection of the equipment best suited for each company must be made by the Quality Department. Since each piece of this equipment is expensive and unique, decisions must be based on application, operator familiarization, maintenance and economic considerations.

To further compound the situation are two new innovations: Automatic Adaptive Control of Machine Tools and Group Technology. Under the Adaptive Control concept, the workpiece will be continually monitored and the necessary adjustments to maintain the required accuracy at optimum machining

rates are automatically made. Group technology consists of grouping families of similar parts so that they can be produced more efficiently. Quality Assurance inputs during the definition and design stages of both of these programs are necessary to insure a successful implementation.

The building blocks for tomorrow's quality programs must begin to be carefully selected today if we are to be successful tomorrow. This must begin with personnel, not only fully knowledgeable of today's requirements, but also with sufficient knowledge of computer technology-related systems currently under development to maintain pace with manufacturing advancements. Old concepts must be re-evaluated and adjustments be made accordingly.

The computer has provided us a tool with which we can produce goods and services at a fraction of the time previously required. To assure that these goods and services are continually produced in a prescribed manner requires a system of controls and quality assessments. In order to design and maintain this system of controls and quality assessments, a knowledge of the computer technology-related manufacturing principles must be present.

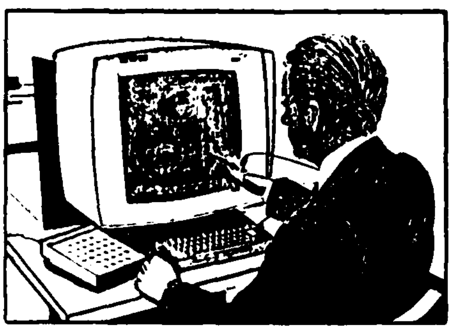


Figure 1

Graphic Display Console

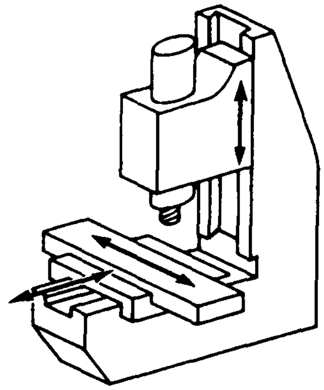


Figure 2

Basic Machine Movements

SUMMARY OF ISSUES AND RECOMMENDATIONS

THE CRAFTSMANSHIP WORKSHOP

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Craftsmanship Shortage

<u>Issue</u>

Lack of skilled craftsmen
- Aerospace
- Nationally

Industry's blue collar work force is aging. New highly qualified people must be developed to replace them.

<u>Recommendations</u>

o For critical crafts
- Apprentice training-contract line item.
- Proposed legislation required.

o A broad training program must be established for crafts and trades.

o More extensive use must be made of the "pink collar" work force.

o Skill qualification training must be stressed.

o Job proficienty demonstration must be ongoing.

2. Quality in Source Selection

<u>Issue</u>

Raise emphasis on quality in government source selection process.

<u>Recommendations</u>

o Past quality performance of a contractor should be given more weight during source selection.

o Specific criteria should be emphasized more in the evaluation of contractor's past quality performance.

3. SOW Clarity

<u>Issue</u>

Statement of work (SOW) clarity on specifications.
- cost driver

<u>Recommendations</u>

o SOW's should clearly specify:
- mandatory compliance vs reference specifications
- applicability of subtier specifications

4. Computer Format

<u>Issue</u>

The aerospace industry does not have a common computer format for CAD/CAM/CAT.

<u>Recommendation</u>

o Industry and government establish a common computer format for CAD/CAM/CAT.
- need industry/government committee

5. PRR's

<u>Issue</u>

Regulation 84-2 on production readiness review should be updated. Production readiness review (PRR) needs updating to accomodate low volume programs:
- presently related to dollar value
- tailoring option not being fully implemented.

<u>Recommendations</u>

o Update language for clarity and incorporation of latest experience.

o Update structure/format to allow for tailoring.

o Emphasize tailoring PRR for small programs.

- PRR should be addressed in RFP.

6. Workmanship Standards

Issue

Government workmanship standard being developed without apparent inter-departmental and agency inputs.

Expediency lacking for state-of-the-art changes.

Recommendations

- Expand committee membership
  - design (packaging) and manufacturing engineering inputs
  - NASA, Navy participation
- Committee to address change and sustaining process.

7. Quality Planning

Issue

Lack of quality planning and evaluation during development results in unanticipated problems showing up in later contract phases. phases.

Recommendations

- Develop a requirements document for the development phase stressing quality planning function.

8. MIL-STD-1535A

Issue

MIL-STD-1535A is an unnecessary cost driver based on current experience.

Basic requirements covered in other specifications.

Recommendations

- Initiate action to cancel MIL-STD-1535A for future contracts.

9. Corrective Action

Issue

All agencies do not use the same problem reporting/corrective action system.

Recommendation

- Shuttle Program
  - develop uniform problem reporting/corrective action system.

10. Conflicting Specs.

Issue

Obsolete and conflicting specifications exist due to state-of-the-art changes (i.e., MIL-H-6061, ANA 616, and MIL-P-5510C vs MSFC 50M 60240).

- potential technical and cost impact

Recommendations

- Convene joint government/industry committee to review and scope problem.

11. Duplicate Audits

Issue

Excessive and duplicate contractor audits.

Recommendations

- Establish procedures for government wide participation and acceptance of inter-agency audits (AF, NASA, Navy, etc.)
- Tailor audits to include positive as well as the negative.
- Program office should participate in planning of audits.

WORKSHOP G

CONTRACTUAL INCENTIVES

Co-Chairpersons
Mr. Harold E. Sharp
Space Division

Ms: Ann C. Dickson, TRW

Lt. Col. Robert Dalrymple
Space Division

Coordinator
Mr. Joe Purcell, NASA

Introduction	Lt Col Dalrymple
Industry Viewpoint	Mr. James B. Gordon Mgr. of Profit Planning TRW, Inc.
<u>Award Fee</u> AF Program Manager's Viewpoint	Col Donald W. Henderson Deputy for Navigation Systems Space Division
Industry Viewpoint	Mr. Richard M. Randall Director, Business Mgmt McDonnell Douglas Astronautics Company-West
Value Engineering	Mr. O.J. Vogl Manager, Value Engineering Hughes Aircraft Co.
Design to Cost for Embedded Computer Systems	Mr. John B. Munson U.P. Corporate Software Engineering Systems Development Corp.
AFSC Incentive Policy and Space Division's Incentives	Mr. Harold E. Sharp Director of Pricing Space Division

INTRODUCTION

Lt. Col. Dalyrmple
Space Division USAF

APRIL 1978
MISSION ASSURANCE CONFERENCE

FINDING	ACTION
• HIGH INTEREST RATES AND INFLATION DISCOUNT THE VALUE OF LONG TERM INCENTIVES	• SD IS STUDYING/IMPLEMENTING: - DISCOUNTING (PRESENT VALUE) OF INCENTIVES - ADVANCE INCENTIVE PAYMENTS - EARLIER, LARGER AWARD FEES
• CONTRACTORS SHOULD BE INVOLVED IN DEVELOPMENT OF INCENTIVE PLANS	• INCREASING USE OF DRAFT RFP'S - ENCOURAGE COMMENTS ON PERFORMANCE INCENTIVES, AWARD FEE FACTORS
• GOVERNMENT/INDUSTRY SHOULD JOINTLY EXPLORE THE SPACE SHUTTLE ENVIRONMENT FOR NEW INCENTIVE APPROACHES AND CONSIDERATIONS	• OF CONTINUING CONCERN/STUDY
• MUST AVOID COUNTER-PRODUCTIVE INCENTIVE STRUCTURE	• SPECIAL ITEM DURING CONTRACT REVIEW
• INCENTIVE PLANS SHOULD BE WELL UNDERSTOOD BY ALL PARTIES	• SPECIAL ITEM DURING CONTRACT REVIEW - INCREASED USE OF POST-AWARD CONFERENCE
• INCENTIVES SHOULD BE USED AS A TOOL FOR ESTABLISHING RELATIVE IMPORTANCE OF REQUIREMENTS	• INCREASING USE OF AWARD FEE
• AWARD FEE IS USEFUL AS A "REPORT CARD" FOR CONTRACTOR	• SD IS INCREASING USE OF AWARD FEE - SD HAS PREPARED AN "AWARD FEE CONTRACTING GUIDE" FOR USE OF PROGRAM OFFICES

HOW HAS THE CONTRACTING ENVIRONMENT CHANGED?

- GENERAL SLAY INITIATIVES:
  - MORE FIXED PRICE CONTRACTS
  - MORE USE OF POSITIVE-NEGATIVE "BALANCE"
  - FEWER SOLE-SOURCE ACQUISITIONS
- SPACE SHUTTLE:
  - SCHEDULE/PERFORMANCE BECOMING MORE DEFINED
- RESOURCES ($, PEOPLE) ARE EVEN MORE CRITICALLY CONSTRAINED
- HIGH INTEREST RATES AND INFLATION ARE CREATING EVEN GREATER PROBLEMS WITH TIME VALUE OF INCENTIVE FLOW
- OTHERS?

INDUSTRY VIEWPOINT

Mr. James B. Gordon
Manager, Profit Planning
TRW, INC.

CONTRACTUAL PERFORMANCE INCENTIVES FROM THE CONTRACTOR'S PERSPECTIVE

PERSPECTIVE 1969

I'd like to put the subject of Contractual Performance Incentives into their proper context or perspective and not treat them in isolation from related contractual and real world economic aspects.

1969 DOD & NASA INCENTIVE GUIDE

The subject of Incentive Contracting has been well documented as to concept and proper application, at least **in theory.** However, it is not the guide books which themselves create basic problems...

SELECTION OF CONTRACT TYPES

Instead, it is the application in practice of these basic principles which holds the key to successful incentive contracting. There is some concern on my part that this critical step has yet to be successfully accomplished...

BASIC CHARACTERISTICS OF FIXED PRICE & COST TYPE CONTRACTS

The significant differences between cost type and fixed price type contracts can, and usually do, create substantial financial (negative) repercussions if proper type selection is not achieved...

'79 GAO STUDY (LCD-79-108)

For example, when the contractor exceeds the boundaries of cost performance incorporated into his (typically FPI) contract, the implied technical performance incentive structure is lost...and this has often happened on complex military communication systems.

1972 & 1974 DOD AUDITS INCENTIVE & CPAF

Clearly, many of these applications-or misapplications problems have also been documented and recognized, but not solved, as illustrated by these 1972 and 1974 DOD Audits. So it is one thing to have good principles but quite another to achieve those principles in the real world...

PROFIT '76 GIVETH & DOD TAKETH AWAY

An Historic review of the Defense Industry's profitability was conducted as Profit '76 by DOD with high hopes **for positive answers** and respectable/authoritative data points for new policy development, particularly to assign a role to capital investment in the profit negotiation process...this was done, but at a price...

COST OF MONEY OFFSET

Unfortunately, the net result of the much heralded Profit '76 effort was to retain the profit status quo, so to speak, while at the same time claiming a remarkable breakthrough in encouraging contractors to increase their (cost saving) capital investments. "Cost of Money" was recognized and accounted for, as was a 10% emphasis on capital in the revised Weighted Guidelines. **Revised, that is, to completely** offset (in aggregate) the added reimbursement of Cost of Money. The idea, of course, was much like the carrot tied to the stick tied to the donkey to motivate his performance. That showed how much DOD really thought of defense contractor's financial astuteness...

DOD POLICY IN THE CURRENT ENVIRONMENT

Meanwhile, on a policy level, DOD continues to be concerned with saying the right things in these difficult times. They repeatedly recognize that low average profit rates on defense business is detrimental to the public interest. They know that the best industrial capabilities will be driven away from the defense market if defense contracts are characterized by low profit opportunities.

ENVIRONMENT GENERALLY GETTING MORE SEVERE

But such hopeful concern is a far cry from meeting past problems, much less in accomplishing real redress to the ever deteriorating situation which we face at the present time...

INTEREST RATE CHART

Obviously, a key ingredient of today's malaise is related to the (unrecovered) cost of financing, particularly a growing concern with the DOD's increased use of fixed price type contracts with their characteristic risks and poor (relative to cost type) payments cash flow...

PROFIT/SALES DISTRIBUTION BY CONTRACT TYPE

Far from being a single profit value in practice, realized profits to sales returns are actually quite scattered in their distribution in the real world. This chart from a now dated LMI Study illustrates the uncertainty of achieving any given profit rate, with increasing uncertainty as we move toward the fixed price type contracting...

CASH FLOW EXAMPLE FIXED PRICE VS. COST TYPE

Moreover, what masquerades as "Higher Profit Opportunities" on the fixed price procurements are more than offset by the typically poor cash flow results inherent with the payments practices vis a vis cost type payments. Even with milestone provisions on long term large programs, only a part of this basic inequity is restored to the contractor, and essentially little, if any, (net) improvement results from milestones where the "price" of approval equals the amount of the inequity in the first place...

CASH FLOW RATES OF RETURN

In the real world, on an after tax, after capital investment cash flow basis (no overrun), an 8% cost type contract is incrementally better than an identical project at 15% on a fixed price basis. The resolution of this financial flip-flop is definitely not to restructure the cost type payments to be as bad as the fixed price contracts, but to come to grips with ways to alleviate this obvious contradiction. Thus, the "paper" profits on fixed price contracts can be largely illusory in many cases, without a dime of overrun!

TREND SINCE 1976 OF FIXED CAPITAL INVESTMENT TO SALES

Since many corporations have DOD business as some (usually minor) fraction of their total sales, and since they typically measure financial performance in relation to assets employed or used in producing their resulting profits, the recent dramatic increase in capital assets needed to perform DOD work has created a challenge to retain, much less improve upon past profitability performance in relation to assets, both fixed and cash flow **variable** assets tied up under current fixed price contracting payments rules.

RATE OF RETURN ON ASSETS-SCHEMATIC

Looking at the basic elements of Return on Assets, it is clear that there are limited options/outcomes under circumstances of rising capital employed (fixed & variable) with a profit...

RATE OF RETURN FORMULA

Policy that mandates a constant rate of "negotiated" or going-in "markup" on sales. In order to meet corporate financial objectives which stress...

ROAE-OPTIONS

Improved Return on Assets, you have to either reduce assets or increase sales/ profits enough to keep in their good graces, so to speak. But capital investment and absorption is dramatically increasing today as a result of inflation and technology coupled with more fixed fixed price contracts with accompanying lousy payments, and I would expect many contractors are waking up to this.

NET PROFIT CONTRACT EXAMPLE

While the government typically recognizes only the "big number" or "negotiated"/ contractual profit percentage, the con-

tractor **can keep** only a tiny fraction of this figure in reality, and it is the latter figure on which investment decisions are made, not the former; even without the aspect of "overruns" there is a major distinction to be made between the government's perception of profit from that which the contractor's banker sees...

OVERRUNS NOT LIMITED TO DOD

Obviously, DOD is not the only agency or entity to have cost overruns, as witnessed by this chart. Many other procurements are also afflicted with "unknowns" as well, and yet this remains today-within DOD- a real concern and an unresolved problems as far as its effect on realized earnings is concerned.

UNALLOWABLE COSTS-INCREASING

Many other elements contribute to the basic difference between "markup" profits and real net returns. These costs not recognized/or reimbursed under government contracting (chart) are nonethele s real and significant to a contractor, and cannot be overlooked in any enlightened discussion of decision profitability or true contractual financial performance.

'76/77 DOD NEGOTIATED PROFITS

Therefore, so-called negotiated profits (as used by DOD) have very little significance intrinsically until they are properly placed within their contractual context of unallowables, taxes, investments, cash flow, etc.

FINANCIAL ANALYSIS METHODS

As shown by this summary of Financial Analysis methods from Investment '76 (part of Profit '76), DOD's profit method is last (and least) on the list, with practically no takers (1). The most viable and generally used approach (on major programs) is a net after tax cash flow, time-factored integrated analysis.

GENERAL SLAY'S STATEMENT TO NOMA RE INCENTIVE CONTRACTS

We are told that AFSC intends to favor "balanced" incentive contracts. This translates to mean that the contractor can lose money for poor performance (but no overrun) and win big (also if no overrun) if performance is perfect.

GENERAL SLAY'S YARDSTICK OF INCENTIVE QUALITY

Good results in incentive contracts apparently focus on how low you go on FPI Ceilings and how high you get on share ratios. I would hope that such a statement also presumes a caveat that the balance of the contractual structure is within achievable limits so that whatever incentives there are can in fact operate in practice as well as on a briefing chart.

LMI INCENTIVE CONTRACTING STUDY

In its' study of Incentive Contracting results (May 1968) LMI found no significant correlation...

FINDINGS OF INCENTIVE CONTRACTING STUDIES

Between cost sharing ratios and overruns or underruns. They did find that incentives have not been significantly effective as protection against cost growth on programs--as the latest 1979 GAO Report also confirmed--and that contractors will not sacrifice performance attainment for profit.

STANFORD STUDY (HEMMES)

In this 1969 study, Robert Hemmes notes in his thesis on Economic Motivation of Contractual Techniques that the results demonstrate that the incentive procurement techniques have not improved procurement efficiency and that in some cases strong arguments emerge that these techniques have been dysfunctional.

STANFORD STUDY (BELDEN)

In his Defense Procurement Outcomes Study (also 1969), David Belden concludes that defense procurement outcomes in the incentive contracting environment have not reflected well on the use of incentive contracts. His primary recommendation is to consider and reflect in the pricing arrangement/contract type selection the uncertainties involved in the procurement to avoid mismatches.

BELDEN STUDY-FINIS

Belden quotes an appropriate observation which is just as valid today in placing incentive contracting into its proper perspective when he **says** that DOD's mission is primarily or firstly to defend well and that to buy well comes second. The fact is that the key problem of proper contract type selection has not been nor cannot fully be resolved which inherently precludes perfection in incentive contracting practice.

TRW'S INCENTIVE CONTRACTING SIMULATION

Even if we assume away all the real world problems of proper contract type matching, a look at the real world constraints via our incentive contracting simulation program reveals another set of practical obstacles, particularly in applying the theory of orbital incentives to spacecraft

TYPICAL RELIABILITY CURVES FOR (3) SPACECRAFT

One of the first and most important aspects of lifetime incentives is **that perfection is in fact possible/attainable,** so that for perfect work the contractor receives high rewards. But probabilistically speaking, each spacecraft is imperfect by design and contracts don't impose such requirements of assured performance perfection even if it were theoretically possible-which I believe it is not due to the nature of the complex system being purchased.

COMPUTER RUN-SINGLE PROGRAM SIMULATION RESULT

With the ·eliability taken as a constant assumption, and with a typical 3 spacecraft system and incentive (orbital) structure of + or minus 8% profit, we can simulate the overall net profit which results on a single program to evaluate just how closely profits follow quality. In the first case, the profit totals +4% (for the simulated program and incentive package, including a launch failure resulting in ½ performance incentives payoff for that bird.

COMPUTER RUN-TEN PROGRAM CASE RESULTS

However, for the identical contractor performance inputs, the incentive results (outputs) can and do vary widely under the simulation of actual performance. Remember, this is based upon a co.stant theoretical quality of product. The point is that the inherent uncertainties of the basic product, coupled with the typical incentive plan, and for a small quantity sample (3), clearly produces erratic results ranging from maximum profit to about a breakeven. In short, in the real world, the theoretical advantages/trade-offs just aren't there.

COMPUTER RUN-TABLE, NET TIME DISCOUNTED

Now, if you put even the realized profits in their lengthy time perspective, those fees/profits are halved or more in effectivenes- from today's standpoint. Moreover, ner deduction must be made to red...e these paper profits to net profits for taxes, unallowables, etc. Perhaps it is a good thing contractors don't appear to pay too close attention to incentives after all...Perhaps incentives are like the mirage, lovely to look at from afar but of no substance **in reality.**

ARMING AMERICA (RONALD FOX)

Another fundamental misconception as to profits exists in the present day discussions regarding cost saving investment in the Defense Industry and Profit Policy to encourage same.

COST REDUCTION INVESTMENT-EXAMPLE

Ron Fox uses an example of how cost-based profit policy effectively precludes contractors from making cost saving investments because to do so reduces their profits which are based on costs. This misleading example supplied by the industry in 1971, is unfortunately either incorrect or oversimplified in that the added costs incurred by the new $8 Million investment are not charged against the analysis (the $8 Million investment must save a gross of $18 Million to save a net of $10 Million)

1979 GAO REPORT-ON DEFENSE INDUSTRY PRODUCTIVITY

Obviously, productivity resulting from efficient new investment should be encouraged, and GAO recommends new profit structures to do this, but at the same time retaining a dumb offset principle so that no more profit in total can be obtained; let's see by example what would happen and what then should be done to recognize a basic dilemma...

REAL COST REDUCTION INVESTMENT

If we build on Ron Fox's example, and use the parameters of an actual case from the Investment '76 Study (part of Profit '76), we see a corrected set of investment and net profit results-again without complications of overrun. Using the profit rate on capital, the corrected result clearly penalizes a contractor if a constant 10% profit is obtained on cost after the cost reduction. Instead of 14.3%, the return is now only 9.94% on capital, a dumb move. In column 2, if we use instead the "Profile Mill" investment of $1.8M and attendant cost savings from Investment '76, this smaller investment with 10% cost-based profit returns a reduced capital profit of 12.88%, another dumb result. In column 3 we reverse engineer the Column 2 profit to just maintain the prior 14.3% Return on Capital and solve for contract going-in amount (and rate) needed to retain capital profitability parity. The rate, in this case is 10.85% without benefit of time discount correction factoring (which would raise it about double the increase). Carefully note that the price to the U.S. Government in this case has been reduced from 110 to 108.42, but face value of profit has increased 8½%.

BEFORE/AFTER-10% COST SAVINGS

If we test to see what is needed to bring about a larger cost savings investment, 10% in this example, a constant 10% Rate of Profit (on cost) drastically slashes Return on Capital to 8.71%, whereas a 43½% Profit Rate increase is required (before discounting) to just retain parity on a Rate of Return on assets basis. Note that this translates into something less than a 6% net lower price to the government.

INCREMENTAL CASH FLOW EXAMPLE

The point is that GAO's perception of constant profit percentages on cost cannot begin to cope with the economic/financial realities of investment motivation in a practical way. More capital investment requires more (net) profitability to be a real motivator; otherwise, that key indicator (ROAE) of management's performance will be degraded, in direct conflict with ever increasing goals for improved financial results.

BILL PERRY'S FY '81 CONTRACT FINANCING REMARKS

At the policy level, the criticality of cash flow in motivating cost effective investment has been acknowledged, and recently HQ AFSC has instigated a contract financing survey to determine improvements in contract financing which, if implemented, can go a long way toward solving some difficult problems for both government and industry.

GRAPHICS OF TYPICAL PERFORMANCE INCENTIVE TIMING

Performance incentives come late in the game, and are not directly connected via the present day incentive or product structure to deterministic payoff results.

CASE 2-COMPUTER RESULTS-10 CASES

This is clearly illustrated by the random results under a small sample program of high technical uncertainty coupled with today's incentive structure, as noted in the various studies on incentive contracting, there is far more theory than results in this field...

ANALYSIS METHODS-REVISITED

The government typically uses a nearly extinct form of profit and incentive analysis-undiscounted total profits-which is, as shown, not particularly meaningful to anyone else. The industry, on the other hand, must deal with a far lower and more realistic aspect of profitability, including the time discount factor and cash flow aspects, net of taxes and unallowable costs.

PROFITS AND PRICES

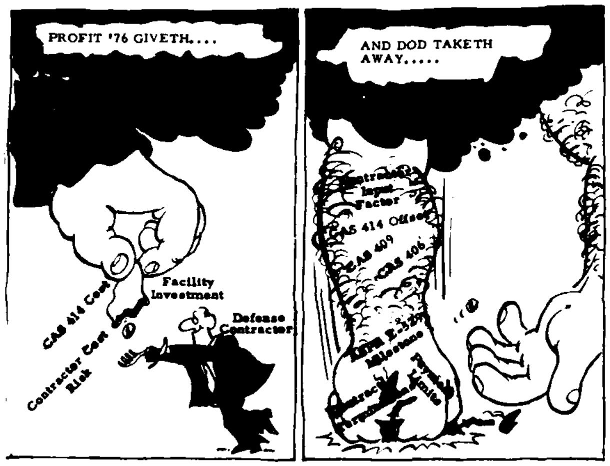
If costs are to be reduced through increased productivity, it is clear that real, not just face amounts, (of) profitability, must rise to encourage this ultimate result. Low profits are not in the government's best interest, nor ours, and much needed real improvement must be made if the desired policy objectives are to be transformed into reality.

DOD POLICY IN CURRENT ENVIRONMENT

"THERE IS A NEED FOR MAJOR IMPROVEMENT IN THE RELATIONSHIP BETWEEN THE DEPARTMENT OF DEFENSE AND DEFENSE CONTRACTORS."

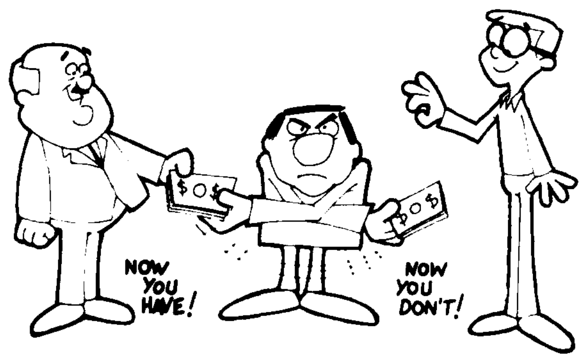
"WE MUST ATTRACT THE BEST AND MOST EFFICIENT CONTRACTORS TO DO BUSINESS WITH THE DOD. IN ORDER TO DO SO WE MUST . . .

- COMPENSATE HIM FOR THE USE OF HIS RESOURCES
- REFLECT THE DEGREE OF RISK INVOLVED
- PROVIDE ADEQUATE RETURN TO THE SHAREHOLDERS
- ENCOURAGE INVESTMENT FOR THE MODERNIZATION AND INCREASED PRODUCTIVITY OF HIS FACILITIES."

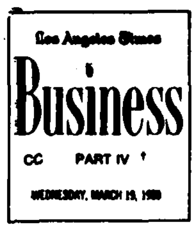


ENVIRONMENT GENERALLY GETTING MORE SEVERE

- INAPPROPRIATE TYPE OF CONTRACTS
- PUNITIVE INCENTIVES
- INCREASED AUDIT SURVEILLANCE
- GENERAL ACCOUNTING OFFICE SURVEYS
- PROFIT LIMITING LEGISLATION
- MARKET SIZE UNCERTAINTY
- OVERHEAD MANAGEMENT
- C/SCSC
- COST ACCOUNTING STANDARDS
- CONGRESSIONAL INVESTIGATIONS

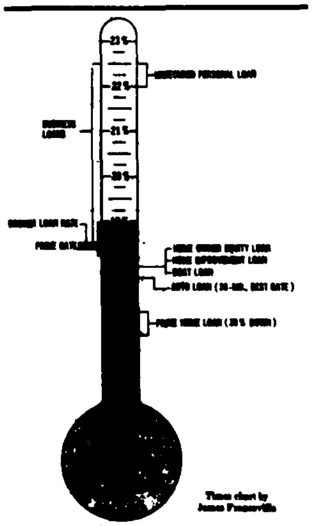


ASPR 3-1300 CAS 414 CONTRACTOR ASPR 3-808 W.G.L.

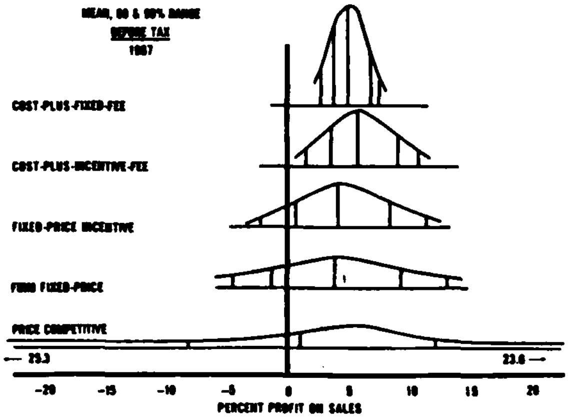

Los Angeles Times

Business

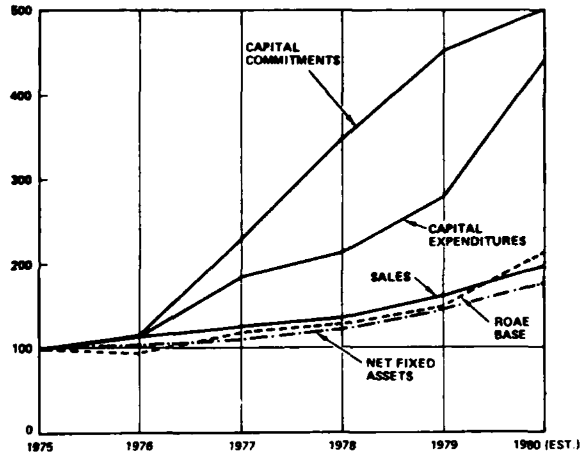
CC PART IV



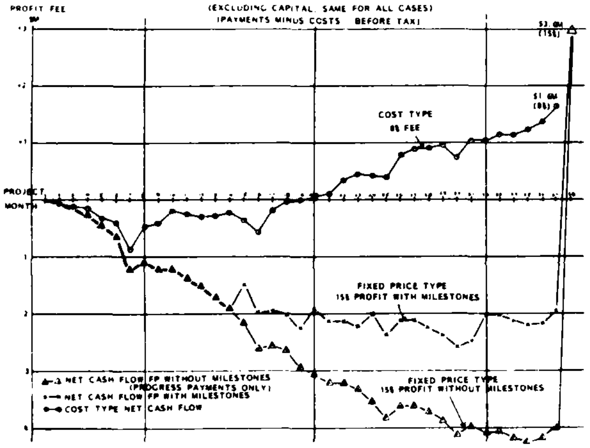
DISTRIBUTIONS OF THE PROFIT TO SALES RATIO BY TYPE OF CONTRACT SALES HIGH AND MEDIUM VOLUME COMPANIES

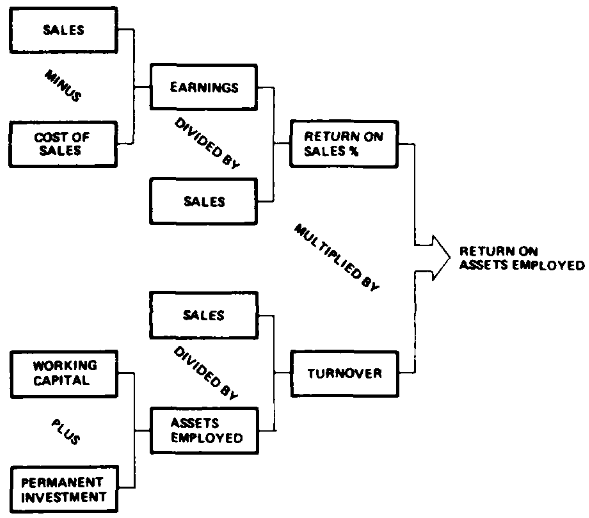


KEY INDICATORS
INDEXED TO BASE YEAR 1975



PROJECT NET CASH FLOW
(EXCLUDING CAPITAL, SAME FOR ALL CASES)
(PAYMENTS MINUS COSTS, BEFORE TAX)





INTERNAL RATE OF RETURN*
COST TYPE VS. FIXED PRICE

	FIXED PRICE TYPE		COST TYPE
COST**	$20.0M		$20.0M
%GROSS PROFIT	15%		8%
PROFIT (B/T)	$ 3.0M		$ 1.6M
CAPITAL	$ 1.1M		$ 1.1M
PAYMENTS	Progress Payments + Milestones + Profit At Delivery	Progress Payments Only + Profit At Delivery	AS YOU GO
RATE OF RETURN	22%	15%	30%
Present Value of Project @ 20% Discount	$887K	$558K	$917K

*Rates of Return Include Project Variable Assets Only, *and Excludes Distributed (Pre Existing) Fixed Asset Base. (If included would reduce listed* Rates of Return by about 1/3rd).

**36 Month Project Delivery at End

RETURN ON ASSETS EMPLOYED (ROAE)

BASIC THEORY

ROAE IS THE MATHEMATICAL PRODUCT OF TWO KEY FINANCIAL MEASURES, RETURN ON SALES AND TURNOVER.

$$\underbrace{\frac{\text{PROFIT AFTER TAX}}{\text{SALES}}}_{\text{(RETURN ON SALES)}} \times \underbrace{\frac{\text{SALES}}{\text{ASSETS EMPLOYED}}}_{\text{(TURNOVER)}} = \text{ROAE}$$

OR

$$\frac{\text{PROFIT AFTER TAX}}{\text{ASSETS EMPLOYED}} = \text{ROAE}$$

RETURN ON ASSETS EMPLOYED

ROAE IS SENSITIVE TO BOTH RETURN ON SALES (MARGIN) AS WELL AS ASSETS EMPLOYED

	SALES	PROFIT AFTER TAX	ASSETS EMPLOYED	ROS	X	TURNOVER	=	ROAE
START								
	$485M	$14M	$116M	3.0	X	4.0	=	12
IMPROVED								
RAISE PROFIT	485	21	116	4.5	X	4.0	=	18.0
LOWER ASSETS	485	14	78	3.0	X	6.0	=	18.0
IMPROVE BOTH	485	18	100	4.0	X	4.5	=	18.0
NOTE:								
WITH THE SAME SALES	485	18	105					17.0
+ OR - $5M INVESTMENT WILL CHANGE ROAE 1%	485	18	95					19.0
	485	17	[illegible]					17.0
+ OR - $1M IN PROFIT WILL CHANGE ROAE 1%	485	19	100					19.0

RETURN ON SALES
THE CONTRACTORS' VIEW OF PROFIT

COST		$100K	
FEE		8	
SALES VALUE	108		
FEE, AWARD ON COST			8.0%
LESS:			
CONVERSION TO RETURN ON SALES	-0.6		7.4
OVERRUN OF 10 PERCENT NO FEE	-0.6		6.8
UNALLOWABLE COSTS	1.0		5.8
NEGOTIATED DISALLOWANCES	0.9		4.9
FEDERAL INCOME TAX	-2.4		
RETURN ON SALES			2.5

OVERRUNS

NOT EXCLUSIVE TO DEFENSE CONTRACTORS

GAO REPORT: 59 NON DoD PROJECTS $780M OVERRUN

OTHER OVERRUNS:

- ALASKAN PIPELINE
- RAYBURN OFFICE BUILDING
- BART
- NEW ORLEANS SUPERDOME
- METRO
- QUEEN MARY, LONG BEACH
- CANADIAN OLYMPICS
- YANKEE STADIUM

+

−

UNALLOWABLE COSTS

- INTEREST
- INDEPENDENT RESEARCH AND DEVELOPMENT
- BIDDING AND PROPOSAL EXPENSE CEILINGS
- ADVERTISING
- CONTRIBUTIONS
- COST OF ACQUISITIONS AND MERGERS
- LEASE COSTS WHICH ARE GREATER THAN OWNERSHIP COSTS
- CAS STANDARD, CORALLARY COSTS ALSO UNALLOWABLE
- NEGOTIATED DISALLOWANCES

NEGOTIATED PROFIT RATES
FIXED PRICE INCENTIVE CONTRACTS

	1976	1977*	CHANGE
ARMY	12.1%	12.5%	+ .4%
NAVY	12.5%	11.3%	-1.2%
AIR FORCE	11.2%	12.0%	+ .8%
DOD TOTAL	11.6%	11.8%	+ .2%

* INCLUDES CAS 414 O

* INCLUDES CAS 414 COST OF MONEY

AWARD FEE
AF PROGRAM MANAGER'S VIEWPOINT

Col. Donald W. Henderson
Deputy, Navigation Systems
Space Division

AWARD FEE

FROM A PROGRAM MANAGER'S NARROW, BIASED VIEWPOINT ∨ BUT SAGACIOUS

WHAT IS INCENTIVIZED?

- COST/SCHEDULE/PERFORMANCE
- RESPONSIVENESS
- SUBCONTRACTOR MGT
- TEST PROGRAM MANAGEMENT
- C/SCSC MANAGEMENT

— — — — — — — — —

- ANYTHING THE PGM MGR WANTS

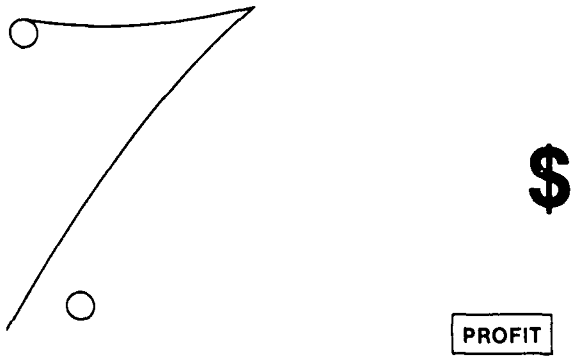
WHY A PROGRAM MANAGER LIKES AWARD FEE

- CONTROL
- GETS ATTENTION
- CAN CHANGE YOUR MIND
- JUST A LITTLE MONEY GOES A LONG WAY
- THE ONLY INCENTIVE THAT WORKS THE WAY IT SHOULD

NAVSTAR GPS AWARD FEE EXPERIENCE

- IT WORKS
- I LIKE IT
- BENEFITS JUSTIFY EFFORT

AWARD FEE — A PERCEPTION DICHOTOMY



CHALLENGE

TO MAKE AWARD FEE A MOTIVATOR AT ALL LEVELS

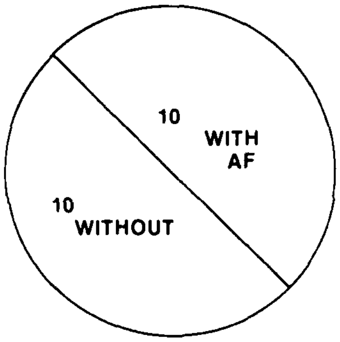
EXAMPLE: CPAF CONTRACT
- 3% BASE FEE
- 12% AWARD FEE

8—12% · EMPLOYEES SHARE
12—15% · EMPLOYEES GET ALL

GPS AWARD FEE EXAMPLES

CONTRACT	BASE FEE	AF	OTHER
FPIF/AF	6.4% TGT	2%	+ 10%
$100 MIL TGT			− 6%
CPAF	3%	12%	
$4 MIL TGT			
CPAF			
$95 MIL TGT	3%	9%	

NAVSTAR GPS AWARD FEE



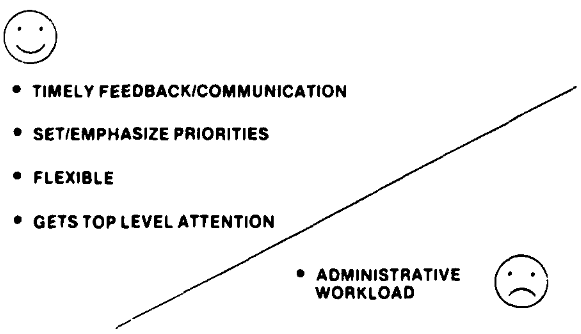
8 FPIF/AF
2 CPAF

20 TOTAL CONTRACTS

GPS AWARD FEE RANGE

- 91% AWARD FEE ($91,700)
  - 10% A.F. + 3% BASE = 13% PROFIT
- 0% AWARD FEE
  - 0% A.F. + 4% BASE = 4% PROFIT

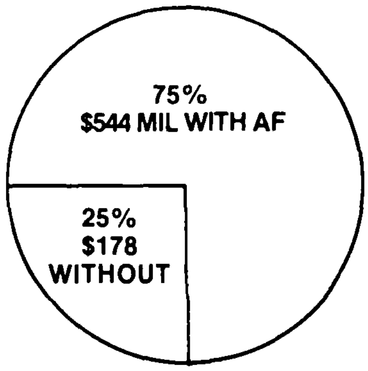
AWARD FEE FROM A PROGRAM OFFICE VIEWPOINT



PROBLEMS WITH AWARD FEE

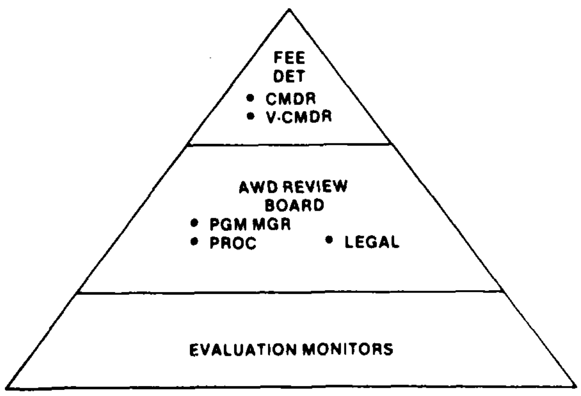
- ADMINISTRATIVE WORK LOAD
- CONTRACTOR PERCEPTION
  - MOTIVATOR/DE-MOTIVATOR

NAVSTAR GPS AWARD FEE



TOTAL CONTRACT $ = $722 MILLION

AWARD FEE DETERMINATION



Richard M. Randall
Director, Business Management
McDonnell Douglas Astronautics Company - West

There are some areas of relevant background material that ought to be recalled briefly, to set the stage for presenting an industry viewpoint on Award Fee Incentives.

First, let's glance at the DAR provision setting forth the criteria for use of the Cost Plus Award Fee type of contract. The main features of DAR 3-405.5 are:

- ° Contract not susceptible to finite measurements of performance for structuring incentive contracts.
- ° Fixed fee (not to exceed 3%) plus award fee (total not to exceed maximum fixed plus award of 10%, except that 15% may be authorized in contracts for experimental, developmental, or research work).
- ° Motivate excellence in such areas of performance as quality, timeliness, ingenuity, and cost effectiveness.
- ° Subjective evaluation by Government based on performance judged in the light of criteria set forth in contract.
- ° Although contract should provide contractor an "opportunity to comment on evaluation," the decision is unilateral and non-disputable.
- ° Applicable to level of effort contracts for performance of services and to contracts which would have been of another type if performance objectives could be expressed in advance by definitive milestones, targets or costs susceptible of measuring actual performance.

Award Fee Incentives were discussed during last year's Mission Assurance Workshop and observations recorded then are probably germane today. Thus, let's consider several of those observations:

- ° USAF acquisition study reveals that industry unanimously favors award fees because:

  They like a "report card" and it is extremely useful to program managers and award fees force strong communication links between the contractors and the Government.

- ° In R&D contracts, incentivizing administrative features may cause the contractor to emphasize these areas at the expense of performance.
- ° The potential motivational value of award fees should be balanced against the resulting administrative cost and effort.

Project Vanguard has considered, and made impressions on, contract methods and practices. Award fees got passing attention in General Slay's April 1979 message to industry which referred to the following areas of concern in contracting:

- ° Move towards commercial contract methods and practices:
  - ° FFP for production.
  - *° In R&D selectively use fixed cost, best efforts contracts with award fee provisions (competitive prototyping).
  - ° Use warranties covering performance, reliability and maintainability, where requirements and specs are well defined.
  - ° Greater use of past performance for selection criterion.
  - ° More competition, less sole source.

However, award fees did not receive specific mention in the General's March 4, 1980, updating message to industry. For the record, he did single out for reference, the following contracting initiatives:

- ° More competition.
- ° Increased use of fixed-price contracts.
- ° Tighter incentive contracts.
- ° Greater use of warranties.
- ° Heavy weighting of past performance in source selection.
- ° Use of draft RFP's.
- ° Multi-year contracting and "a few others.

The topics I chose to discuss during my remarks include:

° Use of award provisions to add to objective incentives to enhance mission assurance.

° Use of "over-and-above" award provisions with CPIF, FPI or FFP contracts (DAR 3-405.5(h)).

° SGS-II as an example of combined, motivational incentive features.

DAR 3-405.5(h), "Other Application of Award Fee Provisions" provides the following guidance and admonition:

° DAR 3-405.5(h), "Other Application" of Award Fee Provisions.

° Use to motivate and reward for management performance "over and above" that which can be objectively measured and incentivized. Areas for application include:

 Logistics support
 Quality
 Timeliness
 Cooperation
 Ingenuity
 Cost effectiveness

° Don't use award fee provisions in conjunction with "other types" of contracts when the administrative effort or costs for evaluation exceed the benefits to be derived.

In my opinion, this utilization of the award fee incentive offers more potential for meaningful motivation than the DAR provisions dealing with the use of CPAF contracts generally.

The SGS-II contract with Systems Division contains what I consider to be a simple, effective combination of commercial features, fixed-price format, no-nonsense schedule and performance incentives and "over-and-above" award fee that can be earned by superior program management. Here is a digest of the contracts incentive and award features:

° Firm Fixed Price contracts.

° Incentives - negative only - established on schedule and mission performance.

° Schedule:

Delivery of hardware to VAFB and readiness for launch (graduated depending on days late to schedule) (2%).

° Mission performance:

All or nothing penalty based upon performance against target performance parameters (10%).

° Awards established on management in areas of:

A) Program management

B) Program integration

C) Test and evaluation

D) Launch support services

E) Systems effectiveness

° Award fee assigned up to 6 milestones (depending on option exercise), each about 9 months apart with allocations of from 10% to 25% of total pool (3%).

Finally, I must take advantage of the opportunity to make some personal comments based upon my experiences with award fee contracts with a number of Government agencies:

° They do get management's attention and may motivate in wrong directions.

° Evaluators have downgraded awards for reasons outside the purview of stated evaluation criteria.

° "Report cards" may cause confusion and bitterness.

° "Cooperation" is important, but too much can be expensive.

° "Working for tips" can place form over substance. (Good service does not compensate for a bad meal.)

° Define what's really important and put the bucks there.

VALUE ENGINEERING

Mr. O.J. Vogl
Manager, Value Engineering
Hughes Aircraft Company

VALUE ENGINEERING AND DESIGN-TO-COST INCENTIVES

Because of the successful application of Value Analysis in shipbuilding, the government introduced in the Armed Services Procurement Regulation (ASPR) clauses to encourage contractors to submit contractual changes that would reduce government costs. The clauses offered contractors a share of the savings effected by an accepted proposal. The development and implementation costs of the changes are deducted from the gross savings to determine the net savings to be shared.

The ASPR - now changed to Defense Acquisition Regulation, DAR, defines the Value Engineering Change Proposal (VECP) as: A change to the contract that results in reducing government costs. A contractor participates in the sharing of accepted VECPs in accordance with the percentage associated in the DAR with the type of clause and the type of contract.

Two types of Value Engineering Clauses are specified:

1. A Value Engineering Program Requirement Clause.
   The contractor is paid, by line item in the contract, to perform Value Engineering. A formal organization and program are required; there is a Military Specification to be met.

2. A Value Engineering Incentive Clause: The contractor is not required to perform Value Engineering studies but is encouraged to do so. He is not paid to do it, but does receive a larger share in the savings of accepted Value Engineering Change Proposals (VECP).

Design-to-Cost Interface with Value Engineering

The DAR Value Engineering clauses do not encompass the same scope as the Design-to-Cost clauses. D-T-C is applied to the contract elements - work break-down structure - to have the contractor meet a specified cost for the manufactured system. The changes made by the contractor are within the limits of the contract. VECPs are all out of scope changes - changes to the contract to reduce costs. Contractors employ the Value Engineering methodology to meet their D-T-C goal, but such changes do not require contractual changes.

To avoid duplication of awards to contractors one of two methods may be used:

1. Each accepted VECP reduces the D-T-C goal by the savings proposed in the VECP.

or

2. No VE award is given the contractor until he has met his D-T-C goal. After the D-T-C goal has been achieved, the contractor shares in subsequent savings.

GAO Report

In 1979, the Government Accounting Office issued a report showing the shortcomings of the services savings under the DAR VE clauses. In response the Secretary of Defense issued a memorandum establishing an annual goal for VECP savings in each service. This goal is 7/10% of each service's procurement dollars.

VALUE ENGINEERING CHANGE PROPOSAL (VECP)

VECP

- **A VECP IS A COST REDUCTION PROPOSAL SUBMITTED UNDER A VE CONTRACT CLAUSE**

THAT IF ACCEPTED WILL:

- **REQUIRE A CHANGE TO THE CONTRACT**
- **REDUCE THE OVERALL COST TO THE CUSTOMER**

A VECP MUST INVOLVE SOME CHANGE IN THE CONTRACT:

- SPECIFICATIONS,
- PURCHASE DESCRIPTION
- STATEMENT OF WORK
- GENERAL AND SPECIAL PROVISIONS
- OTHER ITEMS

A VECP MUST INVOLVE SOME CHANGE IN THE CONTRACT:

- SPECIFICATIONS,
- PURCHASE DESCRIPTION
- STATEMENT OF WORK
- GENERAL AND SPECIAL PROVISIONS
- OTHER ITEMS

SHARING OF V E SAVINGS ACCORDING TO TYPE OF CONTRACT

TYPE OF CONTRACT	*INCENTIVE CLAUSE GOV'T/CONTR	*PROGRAM CLAUSE GOV'T/CONTR
FIXED PRICE (OTHER THAN INCENTIVE)	50/50	72/25
FIXED PRICE INCENTIVE (FPI) OR COST PLUS INCENTIVE FEE (CPIF)	65/35	80/20
COST PLUS AWARD FEE (CPAF)	75/25	85/15
COST REIMBURSEMENT (OTHER THAN CPIF AND CPAF)	75/25	85/15

CONTRACTOR'S SHARE OF COLLATERAL SAVINGS IS 20% FOR AVERAGE OR TYPICAL YEAR OF USE.

*SHARING IS SAME FOR INSTANT AND FUTURE ACQ

VECP SAVINGS

INSTANT CONTRACT - COST REDUCTION ON CONTRACT UNDER WHICH VECP IS SUBMITTED.

CONCURRENT CONTRACT - COST REDUCTION ON OTHER EXISTING CONTRACTS AFFECTED BY THE VECP.

FUTURE CONTRACTS - COST REDUCTIONS ON ALL QUANTITIES NOT UNDER CONTRACT ON DATE OF VECP ACCEPTANCE.

COLLATERAL SAVINGS - GOVERNMENT SAVINGS IN MAINTENANCE, OPERATION, LOGISTIC SUPPORT, OR GOVERNMENT FURNISHED PROPERTY.

GOVERNMENT/CONTRACTOR BENEFITS

CONTRACTOR	GOVERNMENT
INCREASE EARNINGS ON CURRENT AND FOLLOW-ON CONTRACTS	REDUCE CONTRACT COST COMMITMENTS
INCORPORATE NEW TECHNOLOGY	PROVIDE FUNDS FOR NEEDED CHANGE
ENHANCE COMPETITIVE POSITION	PERMIT TECHNOLOGY UPGRADE
DELETE UNNECESSARY/ COSTLY REQUIREMENTS	PROVIDE INCREASE IN PRODUCT CAPABILITY
EXPAND MARKET POTENTIAL	REDUCE COST OF OPERATION AND SUPPORT
REDUCE OVERRUN	REDUCE OR ELIMINATE NON COST EFFECTIVE REQUIRE-MENTS
IMPROVE CASH FLOW	KEEP PROGRAM SOLD

GAO REPORT

POTENTIAL FOR VE SAVINGS IN DoD:	$250 MILLION/YEAR
ACTUAL - 1963 - 76	$700 MILLION
5 PROGRAMS:	$ 24 MILLION IN 1976
1 PROGRAM :	$ 50 MILLION IN LAST 6 YEARS

MOST MAJOR DoD PROGRAMS HAD <u>NO</u> VE SAVINGS.

IN 1976 ONLY 24 (OUT OF 88) MAJOR DoD PROGRAMS REPORTED VE SAVINGS

ARMY	10 PROGRAMS
AIR FORCE	10 PROGRAMS
NAVY	4 PROGRAMS

DESIGN TO COST FOR EMBEDDED COMPUTER SYSTEMS

Mr. John Munson
V.P. Corporate Software Engineering
Systems Development Corporation

APPLICATION OF DESIGN-TO-COST CONCEPT

- OPERATIONAL CAPABILITY DETERMINED BY AVAILABLE DOLLARS
- COST AS A FACTOR EQUIVALENT TO TECHNICAL CAPABILITIES
- ESTABLISHMENT OF DESIGN-TO-UNIT-PRODUCTION-COST GOALS
- TOTAL LIFE-CYCLE COST AS A SELECTION CRITERIA

APPLICATION OF DESIGN-TO-COST CONCEPT

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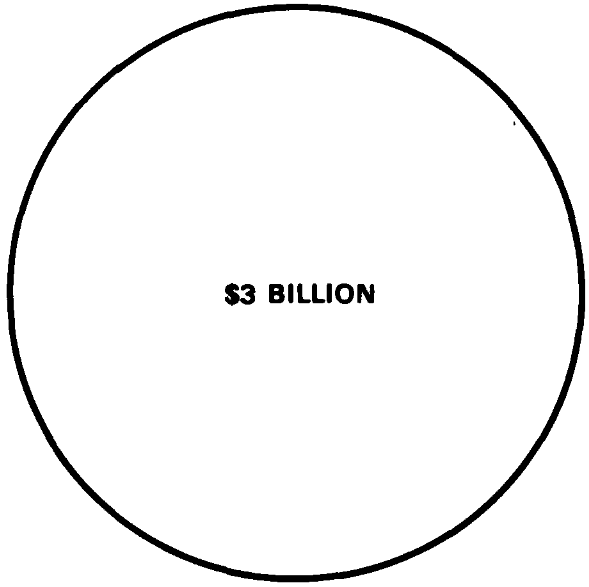
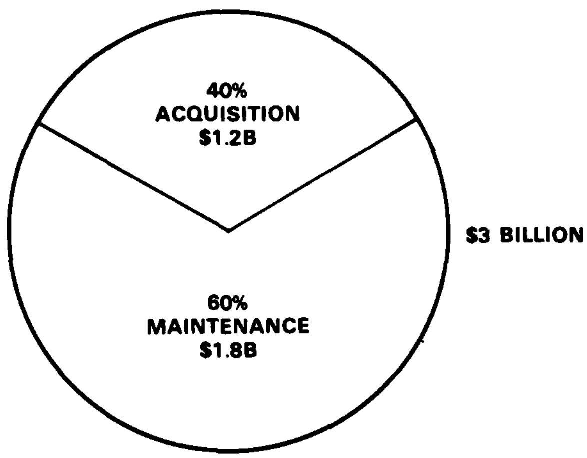
SOFTWARE FOR EMBEDDED COMPUTER SYSTEMS

- SOFTWARE PROVIDES MAJOR SYSTEM FUNCTIONALITY
- GENERALLY "ONE-OF-A-KIND"
- APPLICATIONS SOFTWARE NORMALLY UNIQUE
- NO PRODUCTION CYCLE (AT LEAST FOR SOFTWARE)
- SOFTWARE ALWAYS ON CRITICAL PATH AND IS HIGHEST RISK ELEMENT
- LIFE-CYCLE COSTS A MAJOR SOFTWARE ISSUE

DoD SOFTWARE BUDGET



DoD SOFTWARE EXPENDITURE



CONCLUSION RE: DTC IN EMBEDDED COMPUTER SYSTEMS

THE LIFE-CYCLE COST CRITERIA IS CLEARLY THE MOST REALISTIC SELECTION ALTERNATIVE FOR ACQUIRING EMBEDDED COMPUTER SYSTEMS

. . . BUT IS IT POSSIBLE?

NOT IN ANY PRACTICAL MEASURE TODAY

WE CAN ONLY "BUY" PERFORMANCE!

OUR CONTRACTUAL AND TECHNOLOGICAL TOOLS ARE INADEQUATE TO MEANINGFULLY PROCURE LIFE-CYCLE COST ATTRIBUTES

CHARACTERISTICS OF SOFTWARE

- SOFTWARE IS INTANGIBLE—NEVER EXISTS PHYSICALLY
- SOFTWARE RELIABILITY IMPROVES WITH USE
- CORRECT S/W NEVER FAILS
- REPAIR MEANS CHANGE BASELINE
- EASY TO CHANGE—HARD TO CHANGE—RIGHT
- SOFTWARE FAILURE IS UNPREDICTABLE

FOR SOFTWARE, LIFE-CYCLE COST CONSIDERATION MEANS CONCERN FOR THE MODIFIABILITY ATTRIBUTES OF THE DELIVERED SYSTEM

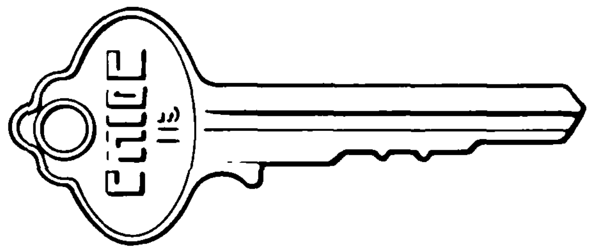
MODIFIABILITY ISSUES

1. CONTRACTING FOR MODIFIABILITY
2. TECHNIQUES FOR BUILDING-IN MODIFIABILITY
3. POST-DELIVERY TEST FACILITIES & SUPPORT TOOLS
4. DOCUMENTING FOR EASE OF MODIFIABILITY
5. QUALITY ASSURANCE OF MODIFIABILITY

MODIFIABILITY STARTS WITH THE CONTRACT

- SET MODIFIABILITY AS CONTRACT REQUIREMENT & INCENTIVIZE WITH AWARD FEE
- REQUIRE S/W MODIFIABILITY DEVELOPMENT PLAN
  - DEFINE DESIGN TECHNIQUES
  - SET PROGRAMMING STANDARDS
  - SPECIFY MANAGEMENT CONTROLS
- REQUIRE S/W MODIFICATION SUPPORT PLAN
  - TEST FACILITIES
  - SUPPORT & TEST TOOLS
- REQUIRE DELIVERY OF ALL DEVELOPMENTAL TOOLS, TEST MATERIALS & DOCUMENTATION

BUILDING MODIFIABLE SOFTWARE



CLARITY & SIMPLICITY

TECHNIQUE

- EMPLOY HIERACHICAL CONTROL STRUCTURE
- ENFORCE MODULAR DESIGN
- UTILIZE SINGULARITY OF FUNCTION
- ISOLATE EXTERNAL ENVIRONMENT
- LIMIT DATA ACCESS
- USE CENTRALIZED DATA STRUCTURES

SOFTWARE "COST DRIVERS"

- USER INTERFACE
  - DISPLAYS
  - REPORTS
  - INPUTS
- EQUIPMENT CONFIGURATION
- LIMITS & CAPACITIES
- EXTERNAL COMMUNICATION FORMATS
- LACK OF PROBLEM DIAGNOSTICS

O & M SUPPORT CAPABILITIES

- ADEQUATE EQUIPMENT RESOURCES FOR TEST
- DATA SIMULATION TOOLS
- ON-LINE DIAGNOSTICS
- DATA RECORDING

REVIEWING FOR MODIFIABILITY

- PLANS & STANDARDS
- SYSTEM-LEVEL DESIGN REVIEWS
- DETAILED [COMPUTER PROGRAM] DESIGN REVIEWS
- AN ADEQUATE TEST PROGRAM
- SYSTEM-LEVEL TESTING
- ACCEPTANCE & DELIVERY INSPECTION

SUMMARY

- THE PRINCIPAL DTC ISSUE IN SOFTWARE IS MODIFIABILITY
- MODIFIABILITY CANNOT BE OBJECTIVELY SPECIFIED
- THE MODIFIABILITY CHARACTERISTICS ARE BUILT IN DURING DEVELOPMENT
- IF YOU DON'T SPECIFY IT IN THE CONTRACT, YOU WON'T GET IT

AFSC INCENTIVE POLICY AND SPACE DIVISIONS INCENTIVES

Mr. Harold E. Sharp
Director of Pricing
Space Division

RECENT SPACE DIVISION CONTRACTS WITH PERFORMANCE INCENTIVES ($ IN THOUSANDS)

PROGRAM/CONTRACT DESCRIPTION	TYPE	SHARE/ PERCENT	% PERFORMANCE INCENTIVES	MONTHLY INCENTIVES PER SPACECRAFT NEGATIVE AMT	NEGATIVE MOS	POSITIVE AMT	POSITIVE MOS	YEARS PAR	YEARS TOTAL	TIME OF PAYMENT
1. DSP/ ONE SENSOR	FPIF	70/30 T.P. 12% C.P. 120%	+ 4.7 -12.0	$55	36	$114	36	1/4	3	FINAL ACCEPTANCE
2. DMSP 3 SATELLITES	FPIF	65/35 T.P. 10.38% C.P. 120%	+21.2 -14.9	68	48	61	36	3	4	AT END OF 3 YEARS QUARTERLY FOR 4TH YEAR
3. GPS/ 4 SATELLITES	FPIF/AF	65/35 T.P. 11% C.P. 119%	+13.0 -15.0 + AWARD FEE OF +6.0	32	78	40*	54	1/4	6½	QUARTERLY AWARD FEE 45 DAYS AFTER NOTIF.
4. DSP/ RETROFIT 4 SATELLITES	FPIF	70/30 T.P. 12% C.P. 120%	+ 11.8 - 16.2	19	120	87	36	3	10	FINAL ACCEPTANCE

* IN ADDITION, ONE TIME NEGATIVE INCENTIVE OF $776 INITIAL OPERATIONAL CAPABILITY IS ASSESSED.

SUMMARY OF ISSUES AND RECOMMENDATIONS

CONTRACT INCENTIVES

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Contract Incentives - High Cost of Money

Issue

The time value of performance incentives is diminished by the high cost of money.

Recommendations

o Continue to make advance payments of incentives with payback provisions.

2. Value Engineering

Issue

Customers are reluctant to fund value engineering programs.

Recommendations

o Investigate increasing the use of V. E. programs and incentive.

3. Imbedded Software

Issue

Existing acquisition regulations, procedures are inadequate for the acquisition of imbedded computer software.

Recommendations

o Investigate ways to properly incentivize software contractors on unique aspects of software performance.

4. Contract Incentives Guide

Issue

There is no current standard guide for incentive/award fee contracting.

Recommendations

o Form a joint Ad-Hoc committee (DOD, NASA, Industry) to write a current guide.

5. Contract Incentives, Award Fee Criteria

Issue

Award fee criteria are not always clearly understood and agreed to with priorities established. Scoring sometimes considers other criteria than those agreed to.

Recommendations

o Keep award fee periods short when possible. For long periods, hold interim status meetings. Follow the award fee plan.

6. Award Fee Pool

Issue

AFSC restricts the carry-forward of unawarded award fee pool for later consideration.

Recommendations

o Pursue modification of restrictive regulations to allow for post-program re-evaluation to award the unawarded fee.

DEVELOPMENT PROCESS
WORKSHOP H

Co-Chairman
Brooks T. Morris - JPL
E.C. Rea - TRW (NAFB)

Co-Chairman/Coordinator
Fred Spiegl - SD

MANAGEMENT APPROACHES

Value Analysis of Quality A Better Product at a Lower Cost	H. Dean Voegtlen Hughes Aircraft Co.
What is Mission Success	V. Woodin Martin Marietta Aero
HEAO Protoflight Approach	James H. Robinson MSFC

TECHNICAL APPROACHES

Thursday, May 1

Voyager Imaging System	R.F. Lockhart & F. Vescelus, JPL
Trade Study on MX Missile Flight Flight Instrumentation	L.D. Swanson TRW
BREAK	
Testing Approach for MX Missile Inertial Measurement Unit	William Lockie Northrop Electronics Div.
QA Approach for ICBM Dormancy/Extended Life	L. Dierking Dr. R. F. Nease Rockwell International

VALUE ANALYSIS OF QUALITY

A BETTER PRODUCT AT LOWER COST

H. Dean Voegtlen

HUGHES AIRCRAFT CO.

ABSTRACT

The nature and objectives of the quality control and value engineering programs are examined. Value engineering is shown to be a powerful tool to achieve overall quality objectives. Some results of VE studies at Hughes Aircraft Company and in other industries are reviewed. It is shown that these results have produced substantial cost reduction as well as other important quality benefits.

PROPERLY APPLIED, THE SCIENTIFIC METHODS used in value engineering/analysis will enhance the quality of products or services supplied in today's market place. This thesis is examined through a comparison of the objectives of both the Quality and Value Engineering programs in general. Specific findings that support the thesis are illustrated through the author's experience at Hughes Aircraft Company.

QUALITY PROGRAM OBJECTIVES

A good definition of the quality function in an organization was stated by A. V. Feigenbaum, a well-known author, teacher, and consultant in the quality field: "Quality Control is a system for administration and coordination of <u>quality maintenance</u> and <u>quality improvement</u> efforts within the organization to enable the manufacture of a product <u>at the most economical level</u> that will allow full customer satisfaction".

Some of the key words are underlined. Quality maintenance includes setting standards or acceptable quality levels, measuring conformance, and obtaining corrective action. Quality improvement involves the setting of goals, development of new quality methods, instilling quality mindedness, and those related tasks needed to raise the level of quality of the delivered product. The final phrase, "at the most economical level", is the real challenge. The value or worth of quality must equal the cost of quality or there will be unhappy customers. Clearly, the quality function's charter must include a strong economic ingredient. Too much quality will bear an unacceptable price; too little quality will result in failure or unacceptable performance in the end-use environment. How can a delicate balance be achieved?

THE VALUE ENGINEERING FUNCTION

A widely used definition of value engieering reads as follows:

> A systematic effort directed at analysis of the functional requirements of systems, equipment, facilities, procedures, and supplies for the purpose of achieving the essential functions at the lowest total cost consistent with needed performance, reliability, maintainability, etc.

The key concepts stated or implied in this definition are function, worth, cost, and value. <u>Function</u> is defined as the specific purpose or use intended for a product or portion thereof. In VE studies the description of function is reduced to the simplest accurate expression employing only two words: a verb and a noun. For example, "support weight", prevent corrosion", and "conduct current" are typical expressions of function.

<u>Worth</u> is the least expenditure required to provide functions needed by the user. Worth is established by comparison. One method of approximating worth is by determining the cost of a functional equivalent. Worth is not affected by the consequence of failure. For example, if a bolt supporting the wing of an aircraft fails, the plane may crash. Nevertheless, the worth of the bolt is the lowest cost necessary to provide a reliable fastening.

<u>Cost</u> is the total funds needed to acquire and use the specified functions. For the seller this is the total of his expenditures in connection with the product. The Department of Defense tends to define this as total cost of ownership or lifecycle cost. It includes acquiring the

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AND WORKSHOPS ON M..(U) SPACE DIV LOS ANGELES AFS CA
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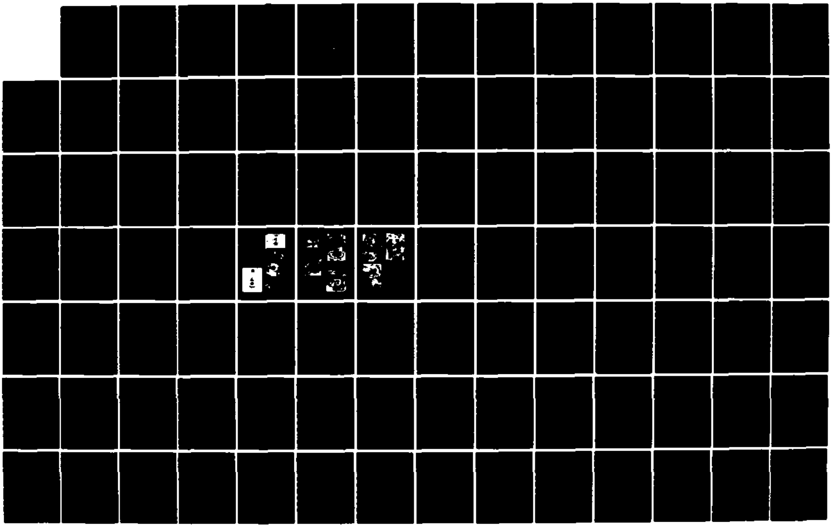

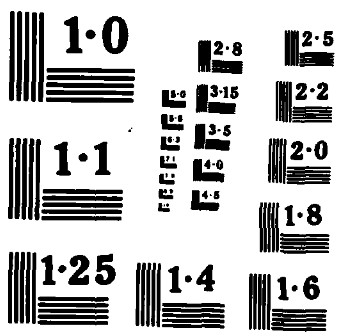

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1·4
1·6

product, introducing it into the inventory, operating it, and supporting it through its usable life.

Value is the relationship of worth to cost as seen by the user. This ratio is the principal measure of value:

$$\text{Value Index} = \frac{\text{Worth}}{\text{Cost}} = \frac{\text{Utility}}{\text{Cost}} \quad (1)$$

Value may be increased by (1) improving utility with no change in cost, (2) retaining the same utility for less cost, or (3) combining improved utility with lowered cost. Optimum value is achieved when all utility criteria are met at the lowest overall cost.

The similarity of concept between quality control and value engineering is obvious. Both programs are aimed at meeting customer requirements at the lowest possible cost. While the quality program is committed to preservation of acceptable standards, the VE program is continually probing to find out if these standards can be met at a lower cost. While quality activities differ from those of value engineering, it is safe to say that a product of acceptable quality as defined above will also have good value. Value engineering can be thought of as a tool to help meet overall quality objectives.

VALUE ENGINEERING AT HUGHES AIRCRAFT COMPANY

For over 20 years Hughes has had an active VE program. It is under the cognizance of the Corporate Director Product Effectiveness. Several other management disciplines are also under this corporate office, including Quality, Reliability, Maintainability, Safety, Data and Configuration Management and Design Standards. While specific activities differ among these programs there are many common objectives and similar management principles involved. Grouping them together under a single Corporate office provides good visibility and a streamlined nonredundant approach throughout the many organizational elements of the Company.

The VE program in brief summary involves workshop training sessions, individual and task team efforts, and generation of lower cost alternatives on company products and supporting activities. There are two distinct areas of work:

(1) On contracts which have formal DOD Value Engineering incentives in accordance with the Armed Services Procurement Regulation 1-17. Savings on approved contract changes are split between the customer and Hughes using the incentive share ratios negotiated in the contract. Hughes now has over 100 contracts in force with VE incentive clauses.

(2) On other programs or company activities where changes do not require customer approval as in (1) above. VE task teams are organized to investigate high-cost areas of the business structure, frequently during the course of new product development and in the formal proposal phases.

Table 1, "Hughes Aircraft Company Value Engineering Performance 1964 - 1979", presents some overall statistics on the program. Formal contract changes as described in category (1) above were incorporated which have cut the cost of contracts by \$373 million over the period. This has been shared in the amount of \$258 million to Hughes customers and \$115 million to the Company. The many hundreds of other cost reduction changes in category (2) above have amounted to an additional \$200 million. These cost savings are about 2.3 percent of gross sales over the period -- a very important ingredient of Company earnings. The customer return on investment is 11 to 1.

VALUE-QUALITY ECONOMICS

It can be argued that value engineering changes, considered only from their economic effect enhance quality. The definition of quality quoted earlier includes the phrase, "at the most economic level that will allow full customer satisfaction". Clearly, quality is improved if the cost is reduced, all other factors remaining unchanged. But most value engineering changes that are well conceived also provide other advantages as well. Table 2, "Value Engineering Changes That Improved Quality", lists a number of typical changes on Hughes programs. Each of these has provided a beneficial quality effect as well as a

cost reduction. These benefits include improved reliability, simplification, easier maintenance, improved performance characteristics, reduced inspection time, and manufacturing process improvement.

For example, numbers 235, 242, 448, 55, 3 and 2 all improved reliability and maintainability through simplification of design and reduction of number of components. Numbers 736 and 146 improved performance characteristics. Numbers 117 and 181 reduced inspection time and provided a standard part in place of a special device, with resultant logistics benefit.

These additional benefits seem to characterize most VE projects. Table 3, "VE Fringe Effects", was prepared from detailed field analysis of several hundred VE changes incorporated into products. The study was made by a task group of the American Ordnance Association (now renamed American Defense Preparedness Association). Producibility and lead time were improved in 90 and 76 percent of the cases studied. Reliability and maintainability were improved 44 and 40 percent of the time. Considering all cases the largest disadvantage found was only 3 percent for logistic effects. The disadvantages combined are so minimal as to be negligible in comparison with the benefits.

CONCLUSION

The value engineering approach to cost reduction through critical examination of functions and development of lower cost alternatives is a proven management method that can produce dramatic savings as well as improved product characteristics. The combined effect can provide a powerful stimulus toward achieving an economic quality level consistent with full customer satisfaction.

TABLE 1 - HUGHES AIRCRAFT COMPANY
VALUE ENGINEERING PERFORMANCE
1964 - 1979

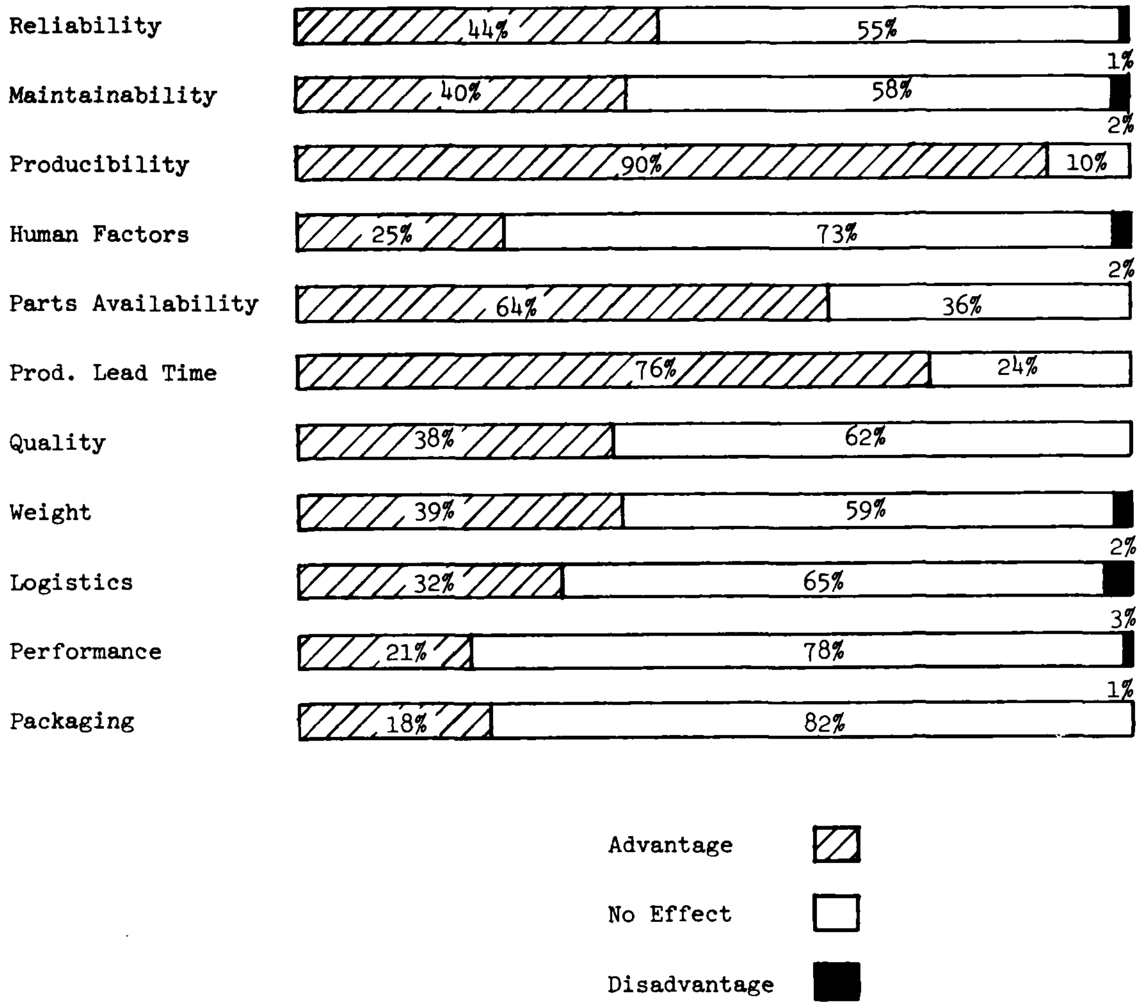
583	VECPs accepted by Hughes customers since ASPR VE contract clauses adopted in 1964
43	Programs on which VECPs were generated
$373M	Total savings negotiated through formal VE changes
2½%	Of sales during period
$258M	Customer Share
$115M	Hughes Share
$23.9M	Overhead funds invested to generate VECPS
11 to 1	Customer return on overhead investment

TABLE 2 - VALUE ENGINEERING CHANGES THAT IMPROVED QUALITY

Program	VECP Number	Description
F-15 Radar	235	Combine RF modules
	242	Simplify switch regulator design
TOW Missile	736	Change plastic reflector to aluminum
	117	Replace meter lamp with standard bulb
	658	Reduce pyro switch sample size
	448	Redesign electrical unit
	518	Modify control surface finish
Maverick Missile	77	Increase shipping container weight
	146	Increase vidicon illumination level
	198	Allow variables and line flow sampling
	181	Change connector to MIL-C-83723
	55	Modify missile power supply/relocate circuitry
407L Ops. Center	135	Reduce number of terminal load assemblies
	138	Simplify design of HV power supply
Sheridan Laser RF	4	Change dip brazing to casting
	3	Replace assembly with one molded part
AN/SPS-52 Radar	2	Simplify antenna design and construction

TABLE 3 - V/E FRINGE EFFECTS

(CLASS I & CLASS II CHANGES CONSOLIDATED)



WHAT IS MISSION SUCCESS?

By: Vernon E. Woodin
Quality Assurance
Martin Marietta Aerospace
Denver Division

I. INTRODUCTION

Mission Success is our way of doing business (Viewgraph #1). When our management discusses Mission Success, they are referring to the ability of our products to perform successfully in the intended mission. Martin Marietta has several product performance histories that demonstrate the Mission Success concept. Our successful performance is a matter of record and as a result, motivates our personnel to the continued emphasis on Mission Success.

High Quality product performance is determined by three basic elements that provide the proper focus for Mission Success (Viewgraph #2). These Mission Success elements are a combination of a System, Discipline and Attitude. The elements are interactive and support each other.

The emergence of the Mission Success concept at Martin Marietta began in late 1965 after the occurrence of errors that jeopardized critical schedules and resulted in functional systems failures (Viewgraph #3). At that time, Martin Marietta management directed an examination of all our assurance systems. The examination revealed the systems were sound and functioning according to documented procedures, but failures were still occurring and problems were escaping our screen. Specific findings were identified which sensitized management to make the necessary changes to adopt the elements of Mission Success. These findings included (a) Multiple Data and corrective action systems existed in Quality Engineering and Reliability Engineering, (b) No specific function existed to interface problem identification to the technically responsible personnel for specific pieces of equipment, and (c) No specific disciplined "second look" by knowledgeable and responsible personnel existed on flight committed hardware.

II. THE ELEMENTS OF MISSION SUCCESS

A. The System -

A program/project environment demands the establishment of a set of minimum acceptable standards.

The Martin Marietta system complies with the Quality Military Specification (Viewgraph #4). The system is documented in company standards and procedures that define the requirements and establish minimum standards. However, we have incorporated within our system some unique features such as emphasis on Quality requirements and planning during early product development and throughout the fabrication/test of the product. These include documented Quality design reviews using checklists, vendor seminars, Special Consideration Items Drawing (SCID), Corrective action that ensures the problem cause is corrected, and Hardware Review/Pedigree of selected items.

The design review checklists provide a disciplined approach to the review which documents the design problems and provides a method of follow-up and documented closure. Our suppliers and subcontractors are brought into our system through vendor contacts and presentation of data at vendor seminars. These contacts impress on the suppliers the importance of Mission Success. We present Mission Success data not only to supplier management but also to their engineers, technicians and Quality personnel. The data demonstrates where and how their particular product affects the final mission. Presenting our concept of Mission Success, how we solve problems, and management attitudes provides a more uniform and consistent program.

Also, this approach brings the suppliers closer to the final product and demonstrates their participation in the end products. The other unique features are discussed later.

Problem Example (Viewgraph # 5)

System components were not analyzed initially, and no requirement in a procurement specification was established until several rejects at the assembly level were encountered. By this time, all units had been delivered. Subsequent analysis established tolerance which was the basis for screening all existing units and for a specification change for future reprocurement. This was a problem that was preventable with disciplined engineering analysis and design reviews. The emphasis on early Mission Success which assures minimal acceptable standards are applied to prevent these failure occurrences.

B. Discipline (Viewgraph # 6)

1. *A strong and uniform insistence on discipline in all organizations is essential to achieve consistent Mission Success.*

   To correct the findings discussed in the introduction, our management elected to (1) combine the existing data and Corrective Action functions into one organization, to focus on the correction of problem causes, (b) Create an environment which interfaces problems/anomalies with technically responsible personnel to assure closeout, (c) Require a disciplined second look on specifically identified hardware (i.e., flight committed), and (d) Provide full visibility of significant problems and impacts. This hardline discipline requires assessment of impact, full customer visibility and assurance that the cause of problems are properly identified and that the corrective action resolves the cause.

2. A set of checks and balances is required to assure that Mission Success goals are being achieved.

   Martin Marietta Management established (Viewgraph #7) a small tightly-knit organization to implement the above corrective measures. This organization is also chartered to provide a continuous evaluation of those disciplines which govern and constitute the Mission Success System. At Martin Marietta we label this organization Mission Success.

   The decision to establish a Mission Success organization was obviously based upon the desire to achieve maximum objectivity. The philosophy underlying this decision was that without specific responsibility being assigned, problems tended to receive less than adequate attention. Mission Success personnel with overall program knowledge and visibility were able to establish meaningful priorities in a multi-functional environment and to interface with all organizational and customer agencies (Viewgraph # 8).

   Three specific areas (Viewgraph # 9) were established within the Mission Success Organization to address Problem Identification, Second Look and Audit Entities.

   Problem Identification and Notification - A Center for problem accumulation and coordination, designed to integrate factory, launch site and vendor organization was required (Viewgraph #10). It was also mandatory that the several organizational elements to be disciplined to notify the Center of project-oriented problems. This became the Corrective Action Control Center (CACC).

Hardware Review - A system was required which identified and insured that designated equipment received a "second look" on an in-line basis (Viewgraph #11). A discipline was established which would force this to occur on a systematic basis. The data resulting from the hardware review became the Pedigree documentation.

Audit - The disciplines which are the essence of Mission Success were identified and an audit plan developed and implemented which would place those systems under continuous monitoring (Viewgraph #12).

These disciplines provide the necessary checks and balances when several organizational elements are involved. It should be pointed out that the disciplines of Mission Success identified above would be performed even if they were not given an organization identity. Specific organizational responsibility provides the attention, focus and objectivity to achieve overall Mission Success (Viewgraph #13).

Example Problem - This problem demonstrates the depth to which our Mission Success Program extends to identify and correct problems to prevent failures in the final product. The evaluation and disposition covered a span of six (6) months.

An assembly failed test in the electronics test area. The failure cause was traced to a single component that had a fractured solder attachment lead to body. A short time later, a module from the same assembly configuration failed the pre-pot test and the same basic component was determined to be the culprit. A Corrective Action Problem Summary was opened to identify impacts against all functional end products. Failure analysis was started, pull tests and twist tests were performed, and microsectioning was accomplished. These investigations indicated voids in the lead attachments and missing body attachments. It was determined from the failed components that only certain lots were at fault. The problem lots were scrapped and suspected components in modules/assemblies as determined from our traceability system, were replaced with good components. Other corrective and preventative measures included changing the assembly process plan to prohibit the use of problem date codes; recommending an automatic-tracking system that statuses part number, date code, quantity manufacturer and purchase order number; and changing the quantity of components subject to pull test within each dash number.

C. Attitude -

1. Mission Success demands an absolute intolerance of failure from all levels of the organization.

Although attitude is being discussed as the third element of Mission Success, it is as important and in some instances, more important than the other two elements (Viewgraph #14). As I mentioned early in this paper, our management considers Mission Success "a way of doing business". Management established as a basic philosophy that no failures would be tolerated for the functional end products. Management must develop a "success oriented" attitude and accept nothing short of success. Management must supply the resources to foster and nurture the "Mission Success" attitude so that the attitude permeates all levels of personnel and is accepted in their day-to-day activities.

When personnel have a Mission Success attitude, the system and the discipline reinforce attitude and conversely, attitude is reflected in the system and discipline.

2. Problems should be aggressively identified, catalogued and given proper visibility to assure management attention and resolution.

   Once the proper attitude toward success was established, the system was required to identify problems, provide documentation, cataloguing and access to data, and notify the appropriate personnel for problem resolution. All possible data sources must be made available for evaluation and problem analysis. A problem identification and notification discipline must be structured to act as a "filter" so that management is not deluged with problems whose nature may be readily handled in a routine manner.

III. SUMMARY -

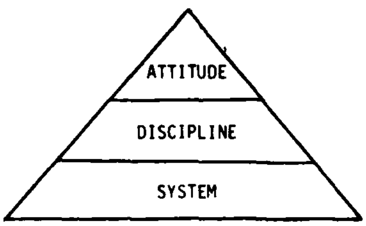
An organization must think Mission Success to obtain success.

Three elements are key to Mission Success - System, Discipline and Attitude. Management must decide on and enforce a policy of intolerance to failures in the final product. They must provide an environment organizationally that enforces and promotes this philosophy. Impact assessment must be accomplished and full visibility provided to management and the customer on significant problems. The customer should be made a part of the Mission Success concept so overall program schedule and cost impacts can be assessed. Usually when the customer is aware of problems, work-arounds or alternate solutions are available to reduce or eliminate overall program cost and schedule impacts. The Mission Success concept is equally applied to the development and test of software products and hardware/software system. Mission Success at Martin Marietta is an essential part of doing business.

WHAT IS MISSION SUCCESS

INTRODUCTION

MISSION SUCCESS



MISSION SUCCESS DEMANDS AN ABSOLUTE INTOLERANCE OF FAILURE FROM ALL LEVELS OF THE ORGANIZATION.

INTRODUCTION

HISTORY - LATE 65

SYSTEM FAILURES CAUSED AN EXAMINATION OF OUR "ASSURANCE" CHECK AND BALANCE SYSTEMS.

OUTPUTS RELATIVE TO MISSION SUCCESS

- o DATA AND CORRECTIVE SYSTEMS EXISTED IN QUALITY ENGINEERING AND RELIABILITY ENGINEERING.
- o NO SPECIFIC FUNCTION EXISTED TO INTERFACE PROBLEM IDENTIFICATION TO PERSONNEL WHO WERE TECHNICALLY RESPONSIBLE FOR THEM.
- o NO SPECIFIC DISCIPLINED SECOND LOOK BY KNOWLEDGE-ABLE AND RESPONSIBLE PERSONNEL EXISTED ON FLIGHT COMMITTED HARDWARE.

THE "SYSTEM"

PROGRAM PLANS INTERFACE SPECS. CONTRACT END ITEMS	DRAWINGS ANALYSIS PDR CDR CHECKING CDRL	PROCESS PLANS PROCEDURES PROCUREMENT MANUFACTURING ACCEPTANCE	LAUNCH FACILITY MISSION OPS. LAUNCH OPS. FLIGHT READINESS
ENVIRONMENTAL DEFINITION AERODYNAMIC (AIR LOADS) THERMAL ACOUSTIC VIBRATION SHOCK STATIC & DYNAMIC LOADS ELECTROMAGNETIC INTERFACE	WORSE CASE ANALYSIS Pc PART DERATING REDUNDANCY Pc PARTS CIRCUITS ELEC. MECH. COMPONENTS SUBSYSTEMS SYSTEMS	PHYSICAL CONFIGURATION AUDIT ENVIRONMENTAL ACCEPT-ANCE TEST PEDIGREE ACRBC AND SCID TRAINING AND CERTIFI-CATION	MISSION SOFTWARE PROGRAMS THERMAL CONTROL TRAJECTORY DISCRETES FLIGHT READINESS FLIGHT ANOMALY MTGS. CAPS MEETINGS
MARGINS OF SAFETY HARDWARE PERFORMANCE		CORRECTIVE ACTION	
QUALIFICATION & RELIABILITY TESTING		FAILURE ANALYSIS	
PAYLOAD INTEGRITY	DEVELOPMENT TESTS	MISSION SUCCESS	
INTERFACE INTEGRITY	PRODUCT INTEGRITY ENGINEER	SUSPECT MATERIAL REPORTS AND GIDEP	

RELIABILITY, MAINTAINABILITY, HUMAN ENGINEERING, SAFETY, CREW SAFETY, QUALITY ASSURANCE, CONT. CONTROL, TRAINING AND CERTIFICATION, AUDIT, SPECIAL SYSTEM REVIEWS, TRENDS, ANOMALIES VS. FAILURES, TEAMS, AWARENESS

SYSTEM

PROBLEM EXAMPLE:

- O SEVERAL REJECTS AT ASSEMBLY LEVEL
  - o System Components Not Analyzed
  - o Component Procurement Specification did not Establish Basis for Screening
  - o All Items Delivered Before Problems Surfaced
- O CORRECTIVE MEASURES
  - o Analysis to Identify Screening Requirements for Component
  - o Changed Procurement Specification for Future Reprocurement

** This problem was preventable by disciplined analysis and minimum standards identification.

DISCIPLINE

A STRONG UNIFORM INSISTENCE ON DISCIPLINE IN ALL ORGANIZATIONS IS ESSENTIAL TO ACHIEVE CONSISTENT MISSION SUCCESS.

- O COMBINE THE EXISTING DATA AND CORRECTIVE ACTION FUNCTION INTO ONE ORGANIZATION.
- O CREATE A FUNCTION TO INTERFACE PROBLEMS WITH TECHNICALLY RESPONSIBLE PERSONNEL AND ASSURE THEIR CLOSEOUT.
- O REQUIRE A DISCIPLINED SECOND LOOK ON FLIGHT COMMITTED HARDWARE.

DISCIPLINE

A SET OF CHECKS AND BALANCES IS REQUIRED TO ASSURE THAT MISSION SUCCESS GOALS ARE BEING ACHIEVED.

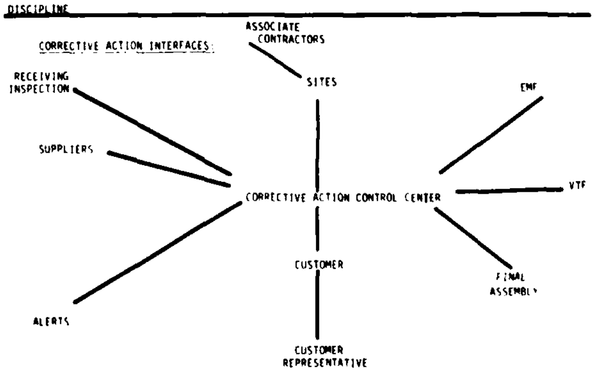
ORGANIZATION SELECTION:

MANAGEMENT DEVELOPED A SMALL, TIGHTLY KNIT ORGANIZATION TO IMPLEMENT:

- o Mission Success
- o Singleness of Objective
- o Concentrated Effort

DISCIPLINE

CORRECTIVE ACTION INTERFACES:



DISCIPLINE

AREAS OF RESPONSIBILITY:

PROBLEM IDENTIFICATION AND NOTIFICATION

- O CACC

DISCIPLINES SECOND LOOK

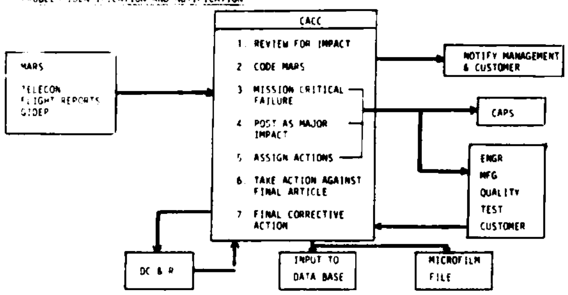
- O HARDWARE REVIEW

CONTINOUS MONITOR OF MISSION SUCCESS DISCIPLINES

- O AUDIT

DISCIPLINE

PROBLEM IDENTIFICATION AND NOTIFICATION



DISCIPLINE

HARDWARE REVIEW PROCESS:

- O RE-EXAMINATION OF ALL DATA ASSOCIATED WITH THE VEHICLE
- O REVIEWS ARE CONDUCTED AT SELECTED MILESTONES IN THE VEHICLE SEQUENCE BY INDEPENDENT PERSONNEL
- O PROVIDES CERTIFICATION OF FLIGHT WORTHINESS

TOOLS USED TO ACCOMPLISH REVIEW PROCESS:

- O IDENTIFICATION OF EQUIPMENTS SUBJECT TO HARDWARE REVIEW
  - SCID
- O PERFORMANCE OF REVIEW AND REPORT PREPARATION
  - COMPONENT AND SYSTEM SUMMARIES
- O SYSTEM IS DISCIPLINED BY EXERCISING CONTROL OF HARDWARE
  - COMPONENT CERTIFICATION
  - INCREMENTAL SUMMARY REVIEW

DISCIPLINE

AUDIT PROCESS:

METHOD OF INDEPENDENTLY ASSESSING DISCIPLINES INTO HARDWARE AND SYSTEMS

- O SUPPLIER SURVEILLANCE
- O HARDWARE AUDIT
- O FACILITY AUDIT
- O SYSTEM AUDIT
- O VERIFICATION AUDITS
- O SPECIAL

DISCIPLINE

MISSION SUCCESS DOCUMENTATION:

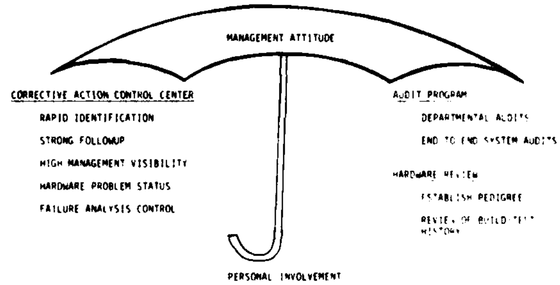
- CORRECTIVE ACTION PROBLEM SUMMARY REPORTS
- COMPONENT PEDIGREES
- INCREMENTAL SUMMARY REVIEW HISTORIES
- PROGRAM STATUS REPORT
- PROGRAM AUDIT REPORTS

REVIEWS:

- WEEKLY MEETING TO DISCUSS MAJOR IMPACT PROBLEMS
- SEMI-ANNUAL PROGRAM REVIEWS
- DESIGN REVIEWS
- READINESS REVIEWS
  - BUILD HISTORY
  - PROBLEMS ENCOUNTERED DURING TEST AND CORRECTIVE ACTION
  - MISSION OBJECTIVES
  - MARGINS
  - QUALIFICATION STATUS

ATTITUDE

MISSION SUCCESS DEMANDS AN ABSOLUTE INTOLERANCE OF FAILURE FROM ALL LEVELS OF THE ORGANIZATION



SUMMARY

- O A PROGRAM/PROJECT ENVIRONMENT DEMANDS THE ESTABLISHMENT OF A SET OF MINIMUM ACCEPTABLE STANDARDS.
- O A STRONG AND UNIFORM INSISTANCE ON DISCIPLINE IN ALL ORGANIZATIONS IS ESSENTIAL TO ACHIEVE CONSISTENT MISSION SUCCESS.
- O A SET OF CHECKS AND BALANCES IS REQUIRED TO ASSURE THAT MISSION SUCCESS GOALS ARE BEING ACHIEVED.
- O MISSION SUCCESS DEMANDS AN ABSOLUTE INTOLERANCE OF FAILURE FROM ALL LEVELS OF THE ORGANIZATION
- O PROBLEMS SHOULD BE AGGRESSIVELY IDENTIFIED, CATALOGUED AND GIVEN PROPER VISIBILITY TO ASSURE MANAGEMENT ATTENTION AND RESOLUTION.

HEAO PROTOFLIGHT APPROACH

James H. Robinson
MSFC

Assessment of the HEAO Protoflight Approach

PREFACE

The HEAO Project employed many special features that were enacted by initial contract to establish a low cost program which would be technically adequate and within an acceptable risk range. Possibly the most significant of the program features is the protoflight concept.

The protoflight concept features building a single set of hardware which serves the purposes of both the ground test model and the flight model. By making maximum use of previously space qualified components developed for other programs, the actual number of test operations could be held to a minimum with most of the testing being done at higher assembly levels of hardware. Analysis played an important role in many of the well established engineering disciplines since it served as the only method of verification in many of the less critical applications or in areas where large design safety factors could be used. Space technology maturity was also a main factor in the decision to employ the protoflight concept.

The experience gained in HEAO flight operations sufficient to assess the protoflight approach as a viable method of qualifying space flight hardware. This document evaluates the HEAO protoflight approach and shows the time and cost savings as well as some disadvantages of not having operational test hardware.

INTRODUCTION AND SUMMARY

1. HEAO Description

The HEAO Project involves three orbital payload mission launches from KSC by the Atlas Centaur launch vehicle at intervals of approximately one year. Each payload consists of an observatory system made up of two sections. One section is the spacecraft equipment module (SEM) containing all the ancillary equipment (subsystems) common to all three missions. The other section is the experiment module (EM) containing a complement of mission peculiar experiments.

The overall physical dimensions of the observatories vary from 14 ft. to 22 ft. long and a diameter of approximately 8 ft. The weights vary from 6500 lbs. to 7000 lbs. The basic observatory designs were completed in 1974.

The basic overall science objectives of the HEAO are as follows:

Map the sky for sources and background of X-rays.

Locate and examine in detail individual X-ray sources and determine intensity, energy spectra, and temporal behavior.

Determine the spacial structure of extended X-ray sources.

Determine intensity, energy spectra and temporal behavior of gamma-ray flux.

Measure energy spectra composition and flux of cosmic rays.

The specific role each observatory plays in meeting the objectives of the overall program is as follows:

HEAO-1 was a scanning mission which made a complete survey of the celestial sphere (all sky) for discovery and location of X-ray sources. Also, some pointings at specific sources were accomplished.

HEAO-2 is a high resolution pointing mission for studying specific X-ray sources in detail.

HEAO-3 is a scanning mission which makes a complete survey for gamma-ray and cosmic radiation.

2. Conventional Method

The conventional concept for developing orbiting payloads featured building two ideally identical articles. The first article, termed the prototype, was test dedicated and preceded the second article long enough to incorporate the knowledge and experience gained into the second article which was the scheduled flight article.

3. HEAO Protoflight Approach

The HEAO protoflight approach consisted of a program formulated by the contractors in 1974 from NASA guidelines

and requirements to develop flight hardware by using a combination of test and assessments for operational qualification involving a minimum of dead-end (test dedicated) hardware. Reliability trades were conducted to select the most cost effective combination and still maintain an acceptable probability of success.

The minimum verification requirements were defined in the beginning and placed on the initial contract. These requirements were identical for all experiments. The spacecraft and observatory[(1)] requirements were different from the single mission experiment requirements since the observatory requirements contained the integration provisions and varied slightly to accommodate the multiple mission applications. The protoflight concept was used for all three observatories.

In order to make the protoflight approach effective, the initial design work gave much consideration to structural strength and operational life. Also, criteria were predicted on the assumption that all electronic piece-parts would be screened prior to fabrication[(2)]. All environments of testing, transportation, handling, launch and operations were considered. Redundancy was employed in critical applications to assure required reliability. A testing program was devised in which all potentially destructive testing was carefully controlled with the environmental levels only slightly higher than those expected during the hardware life. Generous structural and operational margins were used in the design. Test durations at the elevated environmental levels were reduced to preserve the lifetime of the hardware.

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(1) The spacecraft is defined as the supporting structure and the operational subsystems; the observatory is the spacecraft with the experiments installed.

(2) HRA-2001 Assessment of the HEAO Central Parts Control (CPC) Aug. 1, 1978.

4. Significant Findings

The significant findings based on actual experience with the HEAO protoflight approach are as follows:

a. The hardware was qualified for space operations.

b. The reliability was adequate.

c. Significant cost savings were realized.

d. Significant schedule savings were realized.

e. Opportunity for off-line troubleshooting was limited since test hardware was not available.

f. Cannibalization of test hardware to replace failed flight hardware was limited.

BASIC APPROACH

1. General

Each contractor planned his respective verification program within the guidelines provided in the basic contract. Trade studies were conducted to evaluate how much hardware testing could be eliminated by verification through assessment and to identify the hardware level at which testing would give the most desired results (e.g., experiment contractor conducting the test at experiment level or deferring the test to be conducted at the observatory level). These studies also established criteria for conducting the necessary tests. Resulting requirements were coordinated with the other contractors and also judged against the interface control requirements and were eventually approved by MSFC as part of the end item specifications.

The contractors then prepared control documentation in the form of test specifications and procedures. These were reviewed by MSFC and other contractors, and approved for conduct of tests. All

testing was the responsibility of the contractors and was done either at their own facilities or at leased facilities. The testing was done under the surveillance of Government quality representatives.

Although some specific variations existed, the basic approach for the experimenters was to subject the experiment as a unit to the required environments. Minimizing environmental testing at the component level drastically reduced the number of total tests performed. Since the spacecraft is more critical to mission success than an individual experiment, a selected combination of component environmental and system level testing was implemented on the spacecraft.

2. Requirements

A basic set of common requirements was placed on contract and adhered to for all three missions. Any deviation from those requirements entailed action by the contracting officer. Those requirements are summarized as follows:

a. Use proven designs, off-the-shelf hardware, design techniques and emphasis on assessment to minimize the need for testing/retesting. All off-the-shelf hardware and designs were analyzed prior to acceptance for use.

b. Identify lower than system level (parts and components) hardware by study/analysis which requires special development and qualification testing.

c. Perform in-process acceptance and selected environmental testing of flight hardware at lower than system level to reduce the risk of failure at systel level test.

d. Perform qualification/acceptance testing of flight hardware (protoflight approach). Note: the experiments were qualification/acceptance tested at the experiment level prior to delivery to the observatory contractor. After integration into the observatory, the system was subjected to observatory system qualification/acceptance testing.

e. Perform test types with environmental exposures as shown on Table I for experiments and Table II for the observatory. The hardware flow is shown on Figure 1.

3. Types of Tests

a. Development: Development tests were conducted on lower level hardware at the contractors' discretion to verify the feasibility of new design approaches. This was particularly true for experiments since the design of many experiment components was pushing the state-of-the-art. Some simple balloon flights were conducted on selected experiment components in order to verify the instrument scientific capability. All of these served as confidence builders that the final product would perform satisfactorily.

b. In-Process Acceptance: Hardware in-process verification (functional tests and inspections) was performed on lower levels (piece-parts, components, subassemblies, etc.) to establish compliance with drawings and specifications. As the experiments and spacecraft were assembled from lower level hardware, in-process functional tests and inspections were performed to verify each installation. At completion of assembly, a system functional checkout was performed.

*c. Qualification/Acceptance (Q/A): The end item flight hardware was subjected to a combination of qualification and acceptance verification performed at the component or system level. The tests were used to demonstrate that the hardware met all of the

performance and design requirements under anticipated operational regimes and environments defined in the end item specification. While Q/A tests were performed principally on the end items, selected components used in critical applications on the experiments were subjected to Q/A testing. On the spacecraft, forty-eight components were tested for qualification and then refurbished as required and reserved as flight hardware spares.

*Since only one set of each kind of hardware was manufactured, the Q/A test levels were adjusted to assure that the hardware was capable of withstanding anticipated operational environmental levels but not tested to fatiguing levels to determine design margins. Generous safety factors based on analysis were used in the designs. The following data will give insight to the approach:

Design Safety Factors
Fluid lines, fittings, functional components . . . test 2 X operating, ultimate 4 X operating

Pressure vessels ... test 1.5 X operating, ultimate 4 X operating

Structures (no static test)... design yield 2.0, design ultimate 3.0

Vibration (sine and random)... tested 1 min. each axis at upper 2σ flt. level

Acoustic...tested 1 min. at 2σ upper flt. level

Thermal...tested to design operation max + (5 to 10°F) and min. -(5 to 10°F)

Electrical Parts...derated to 0.2 to 0.75 (avg. 0.5) of design value

4. Test Sequence

Figure 2 is a composite chart showing the sequence in which the HEAO was verified beginning with the system/experiment level. Experiment baseline functional tests and final acceptance functional tests embody "on orbit" type commands of all planned modes. Other functional tests were designed to demonstrate experiment integrity after environmental exposure.

After completion of each verification sequence (experiment, spacecraft, observatory), a joint contractor/MSFC review of the qualification status was made to evaluate the readiness to go to the next phase. The results were recorded in an endorsement to the Certificate of Flight Worthiness (COFW). In some cases, the experimenters were able to defer some tests until the experiment was integrated into the observatory. Then the test was conducted at the observatory level (e.g., HEAO-2 experiment vibration and acoustic tests and the HEAO-1 A-1 experiment fluid leak tests). These actions further reduced the overall number of separate tests, thereby effecting a cost saving. These cases were evaluated on an individual basis and recorded in the COFW.

ASSESSMENT

1. Reliability and Performance

A definition of mission success was established in advance of launch. Flight performance then could be measured against that success definition to determine the effectiveness of the mission. While inflight failures and problems occurred (34 incidents in the first 15 months of operations) on HEAO-1, these were either in non-critical applications or in redundant applications which resulted at most in reduced sensitivity or altered the calibration in some of the experiments. The design life of the observatory was six months. After 15 months, all 4 experiments were still acquiring good and useful data although the mission was changed from a "scanning only" mission to a more complex pointing

mission after the observatory was in orbit. No incidents or operational characteristics that would justify a prototype observatory are evident.

In the conventional concept, the tests for the prototype are designed to find design deficiencies, and the tests for the flight article are designed to find workmanship defects. In the protoflight concept, the tests are designed to find both. Since neither design nor manufacture is a perfect science, some inherent differences will exist between the prototype and the flight models. These differences, even when small, can cause concern over whether the flight model is representative enough to withstand the natural and induced environments based on testing the prototype to specified levels alone. Confidence in the protoflight is high, since it has been subjected to the actual environments. Further, there is no evidence that the ground testing created any defects in the protoflight model. In the experience on HEAO, no compelling evidence manifested itself in favor of having a prototype.

2. Manufacturing and Schedule

Figure 3 shows a sample manufacturing and test schedule for a typical HEAO observatory based on initial planning with the actual manufacturing and testing factored in. Non-recurring tasks such as definition, design, launch and mission operations are not shown since those items are common for both conventional and protoflight approaches. For purposes of this report, the hypothetical prototype observatory would be assembled using the prototype experiments. All hardware would be manufactured identical to the flight article except commercial electrical piece-parts would be permitted if preferred screened parts are not available. As can be seen from Figure 3, a schedule time saving of approximately one year was realized. This can be interpreted as an extra year's use of manufacturing and test facilities, maintaining the full complement of manpower for purchasing, contracting, program control, manufacturing, testing and management as well as the cost of purchasing parts, materials, components,etc. for the extra observatory required for the conventional approach. The time saving shown in Figure 3 is considered an average for the protoflight approach over the conventional approach where a single set of support equipment (SE) would be used to perform all testing. A second set of SE would allow some overlap in testing during the Integration and Test (I&T) period, but the saving in time would not be significant since test evaluation of each environmental test on the prototype model would be needed for designing the test for the flight hardware. Also, extra personnel would be required to conduct the parallel testing.

Although HEAO-A was manufactured, tested and delivered to the launch site on the original schedule, launch was delayed almost four months due to a faulty Rate Gyroscope Assembly (RGA).

The natural question which arose was "would that delay have happened if a conventional approach had been used?" This question cannot be answered directly. The RGA electronics was a new design being developed for another space project which was scheduled to precede HEAO-A by some 12 months. That project fell behind with the attending delay in need for RGA's. This positioned HEAO in line for initiating the RGA development for space use.

The RGA purchase order for three HEAO missions was one Engineering Model (EM) and eight flight units. The first unit was scheduled to be used for qualification tests and later refurbished for a flight spare. The manufacturer's delivery was several months behind schedule. Consequently, there was not enough time between the EM testing and flight hardware production to provide full benefit from the EM tests. Even under the above conditions, a significant problem emerged only about two weeks prior to scheduled launch and then only through extended operational tests. With the mission criticality of the RGAs being very high, the decision was made to hold the launch until the generic problems were understood and fixed, although a working flight spare was available. An observatory was not needed to perform the requalification

testing as the offline testing was successful. Prototype observatory testing may not have uncovered the seriousness of the problem since it would not have been scheduled for prelaunch testing, the testing on which the problem was discovered. In that event, the existence of a prototype would not have enhanced the launch schedule. The projected launch schedule for a conventional development approach would have been one year later than the protoflight approach. Assuming that the problem was found in prototype observatory testing and solved without affecting the launch schedule, the protoflight launch was still eight months earlier than it would have been with the conventional approach.

Some disadvantages of not having a prototype exist. In the event of a catastrophic accident such as may occur in transportation or handling or failure to achieve proper orbit, a prototype could be refurbished and launched. In the event of subsystem or component failure, prototype hardware could be cannibalized for the flight vehicle provided that the prototype is of flight quality. Diagnostics for inflight anomalies could be conducted on the ground using the prototype.

3. Cost Evaluation

A study was conducted based on available data to determine what cost savings were realized by using the protoflight concept in lieu of the conventional concept. A ground-rule was established whereby costing covered all aspects leading up to having an observatory ready for launch operations. Costing was put into three main categories: (1) Design and development, (2) Manufacturing and (3) Integration and test. For purposes of this study, the conventional approach would designate the protoflight article as the prototype article and a flight article would be added. Then, the cost differential would be the manufacture, integration and test of the flight article. In assessing the cost differential between the two approaches, it was assumed that due to the hardware manufacturing learning curve, reuse of certain fixtures, etc., the second article would cost 10% less to manufacture than the first article. Further, applying the same principles to integration and test, a 20% reduction in cost was assumed. Based on the HEAO-1 cost data available and the above ground-rules, a program cost increase of approximately 30% could be expected for a single observatory program if the conventional approach is used for development.

CONCLUSIONS

While the protoflight approach is recommended for scientific type space probes, some restraint should be used in its application. The following are lessons learned based on the HEAO experience to date:

1. Define the program and baseline the requirements for the initial invitation for bids. Late changes that require reverification can substantially increase the cost of testing.

2. Give special attention to newly developed items especially where the state-of-the-art is concerned. The new items generally require a qualification model which can be refurbished after testing and used as a spare. Extreme caution must be exercised in using off-the-shelf designs and hardware especially when considering application and reliability.

3. Give special attention to early scheduling and prompt delivery by the contractor of test specifications, procedures, and integration criteria which require coordination and review.

4. Maintain good communications among all participating parties particularly in the interface areas. This may help reduce the overall testing by making each test meaningful.

5. Use selected screened electronic parts to avoid unwarranted early failures. This prevents much retesting resulting from rework.

6. Use only with contractors that are well experienced in space activities and that have adequate technical resources to assure continuity to the end of the program. Contractors who have experienced failures and successes and have analyzed the differences are likely to have the unique knowledge to routinely develop hardware which will operate successfully the first time.

7. Maintain an up-to-date materials and parts list of space proven items. Select as much as possible from that list in order to avoid new developments.

8. Use a conservative design approach to allow adequate margins for test and flight environments.

Based on experience gained during ground test and mission operations on two sets of HEAO hardware, it is concluded that the protoflight approach can be used successfully with attending cost savings and without any compromise in reliability.

EXPERIMENT ACTIVITY	VERIFICATION METHOD COMP (See Note 1)	EXPERIMENT LEVEL	REMARKS
Static Load	Assessment	Assessment	Conservative design eliminated test.
Acoustic	Dev. and Qual Test	Assessment (See Note 3)	Susceptible components tested.
Vibration	Dev. Test (See Note 2)	Qual/Accept Test (See Note 3)	Tested susceptible components. Confirmed math model for exper. in qual/accept test (3 axis sine/random).
Acceleration	Dev and Qual. Test	Assessment	Conservative design eliminated system test.
Thermal Vacuum	Dev Test (See Note 2)	Qual/Accept Test (See Note 3)	Included outgassing, corona and temperature extremes. Tested susceptible components. Confirmed math model in qual/accept test (included thermal balance).
Mechanical Shock	Assessment	Assessment	Low energy ordnance devices used to eliminate need for test.
Mechanical Life	Dev and Qual. Test	Assessment	Established cyclic life on moving mech. component/subsystems.
Humidity	Assessment	Assessment	Provided protection at all sites in lieu of testing.
Press. Profile	Assessment	Assessment	Rise to altitude, rate of pressure change.
Press. /Leak	Dev. Test (See Note 2)	Qual/Accept Test	Proof, leak fluid/gas system. Sealed components performance checks.
Elec. Integrity	Dev. Test (See Note 2)	Qual/Accept Test	Cable insulation. Component/module load isolation, continuity and grounding checks.

(Continued on next page)

TABLE I, HEAO EXPERIMENT VERIFICATION REQUIREMENTS

EXPERIMENT ACTIVITY	VERIFICATION METHOD COMP. (See Note 1)	EXPERIMENT LEVEL	REMARKS
EMC	N/A	Qual/Accept Test	
Magnetic Field	N/A	Assessment	Assessed to ICD requirements.
Mass & C.G.	N/A	Qual/Accept Test	Calculated moment of inertia.
Interface Checks	N/A	Qual/Accept Test	Electrical and mechanical (ICD requirements).
Align. & Calibration	N/A	Qual/Accept Test	• Included prior cleanliness check.
Performance	Dev Test (See Note 2)	Qual/Accept Test	Established initial & final baseline. Checked before and after envir. exposure; operated during exposure as req'd for thermal vac. and mech. life.

NOTES:
1. Components considered qualified by test/assessment were refurbished as spares.
2. Appropriate acceptance tests on components performed prior to assembly into experiment.
3. Type of environmental tests also performed on experiments at observatory level.

TABLE I, HEAO EXPERIMENT VERIFICATION REQUIREMENTS (Concluded)

OBSERVATORY ACTIVITY	VERIFICATION METHOD	REMARKS
Static Load	Assessment	Conservative design eliminated test.
Modal Survey	Assessment	Confirmed by low frequency sine qual/accept vibration.
Acceleration	Assessment	Conservative design eliminated observatory test.
Press. Profile	Assessment	Rise to altitude, rate of pressure change.
Mech. Shock	Assessment	Low energy ordnance devices used to eliminate need for test.
Humidity	Assessment	Provided protection at all times in lieu of testing.
Magnetic Field	Assessment	Assessed to ICD Requirements.
Integration	Qual/Accept.Test	S/C subsystems, experiments interfaces (incl. launch vehicle), support equip. and software physical, functional (electrical/mechanical) compatibility check.
Elec. Integrity	Accept. Test (See Note 1)	Cable insulation. Component/module load isolation, continuity and grounding checks.
Pressure Leak (See Note 2)	Qual/Accept.Test (See Note 1)	Proof, leak fluid/gas system.
Mass & C.G.	Qual/Accept. Test	Calculated moment of inertia. Performed prior to environmental test series.

(Continued on next page)

TABLE II, HEAO OBSERVATORY Q/A VERIFICATION REQUIREMENTS

OBSERVATORY ACTIVITY	VERIFICATION METHOD	REMARKS
Align. & Calibr. (See Note 2)	Qual/Accept. Test	Included prior cleanliness check.
Performance (See Note 2)	Qual/Accept Test (See Note 1)	Comprehensive test established baseline; abbreviated test after each envir. exposure to determine envir. effect; operated during environments as required.
EMC	Qual/Accept Test (See Note 1)	
Thermal Vacuum	Qual/Accept. Test (See Note 1)	Included outgassing, corona, and space simulation. Confirmed math model for observatory, including thermal balance.
Acoustic	Qual/Accept. Test	Shroud off observatory.
Separation Shock	Qual/Accept Test	Observatory - Launch Vehicle separation plane. (HEAO-A only)
Vibration	Qual/Accept Test (See Note 1)	3 axis, low frequency sine. Confirmed modal survey analysis; served as dynamics loads check. (HEAO-A & HEAO-B only.)

NOTES:
1. Appropriate acceptance tests on components performed prior to assembly into the observatory.
2. Denotes pre-environmental functional tests which are repeated after environmental tests prior to shipment.

TABLE II, HEAO OBSERVATORY Q/A VERIFICATION REQUIREMENTS (Concluded)

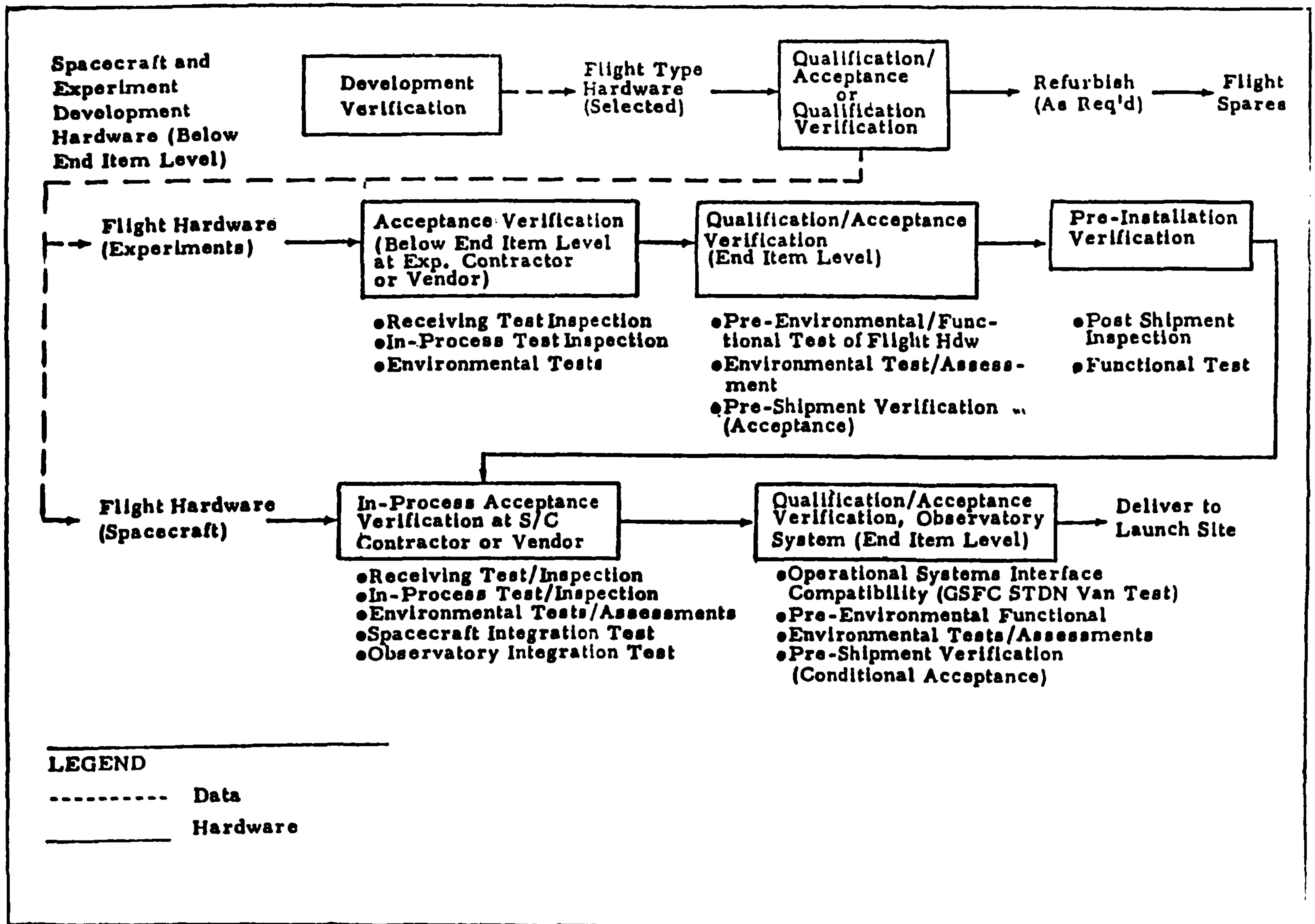

FIGURE 1, HEAO HARDWARE & VERIFICATION FLOW DIAGRAM

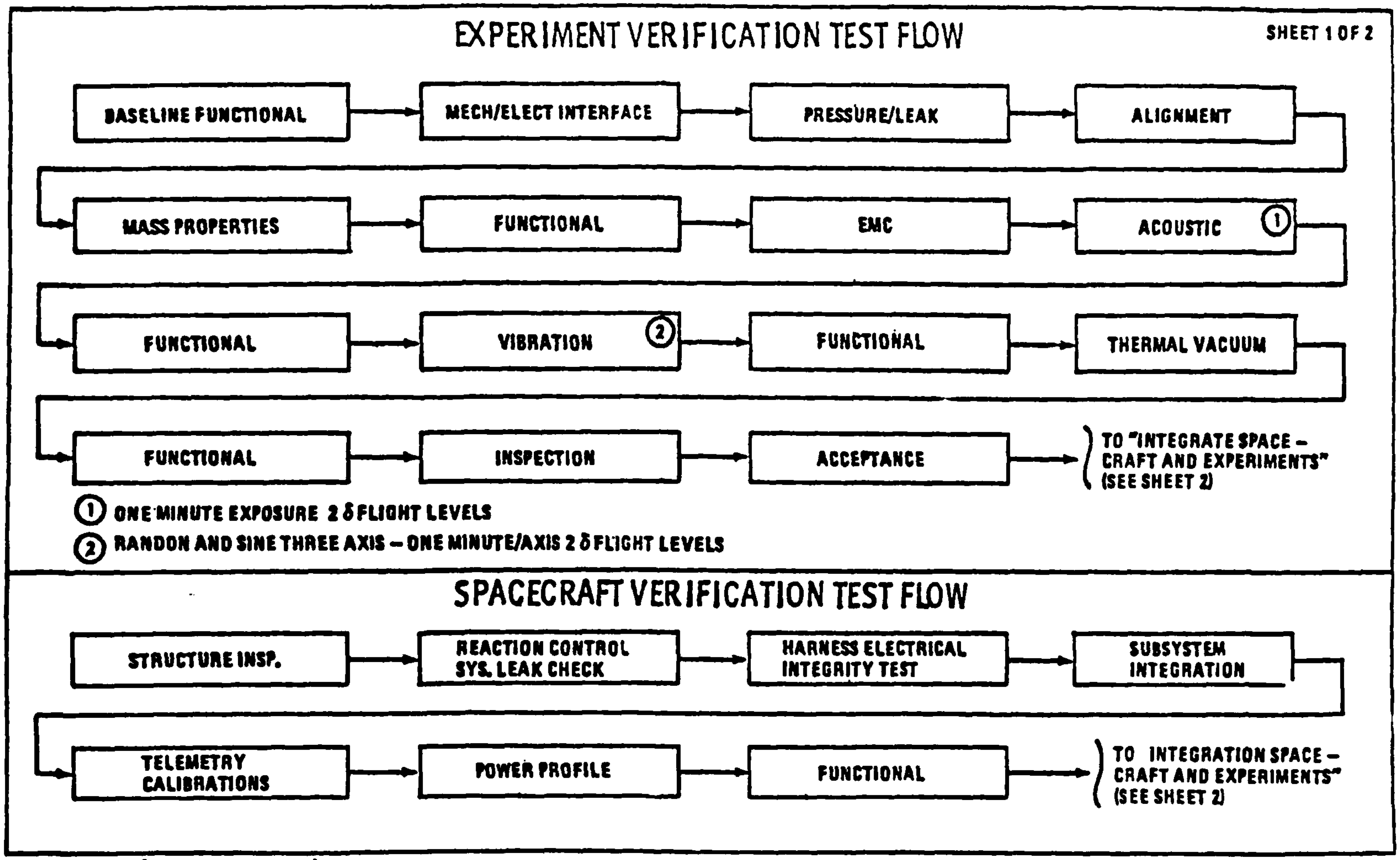

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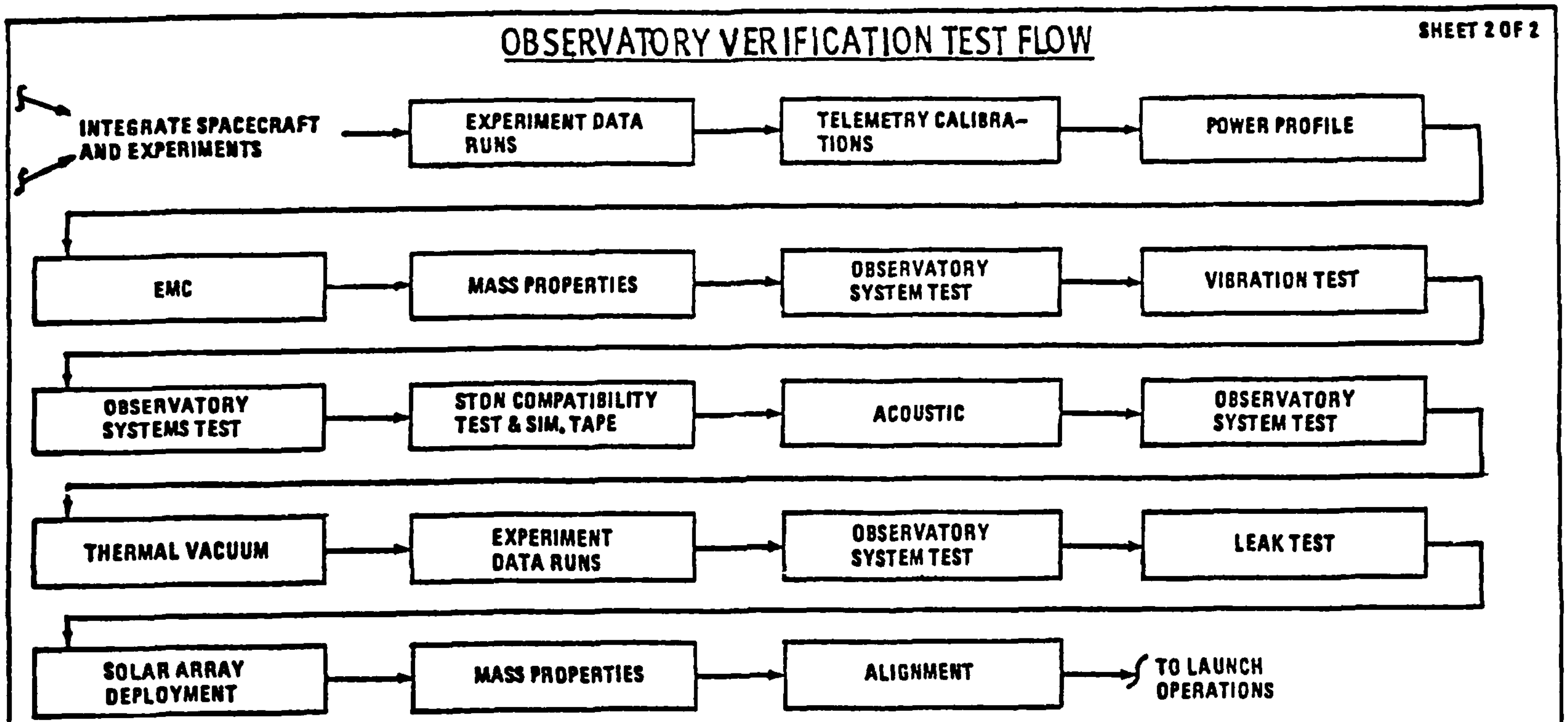
FIGURE 2, VERIFICATION TEST FLOW



NOTES:

1. THE LEVEL I OBSERVATORY (SPACECRAFT AND EXPERIMENTS) ALIVENESS TESTS ARE NOT SHOWN SINCE THOSE TESTS ARE RUN PRIOR TO AND AFTER EACH OBSERVATORY OPERATION
2. THE OBSERVATORY SYSTEM TEST (OST) IS A LEVEL II TEST TO EVALUATE THE SPACECRAFT SUBSYSTEMS AND THE EXPERIMENTS OPERATING AS A UNIT.
3. EXPERIMENT DATA RUNS ARE LEVEL III TESTS CONDUCTED FOR DETAILED EVALUATION OF THE EXPERIMENTS

FIGURE 2, VERIFICATION TEST FLOW (Concluded)

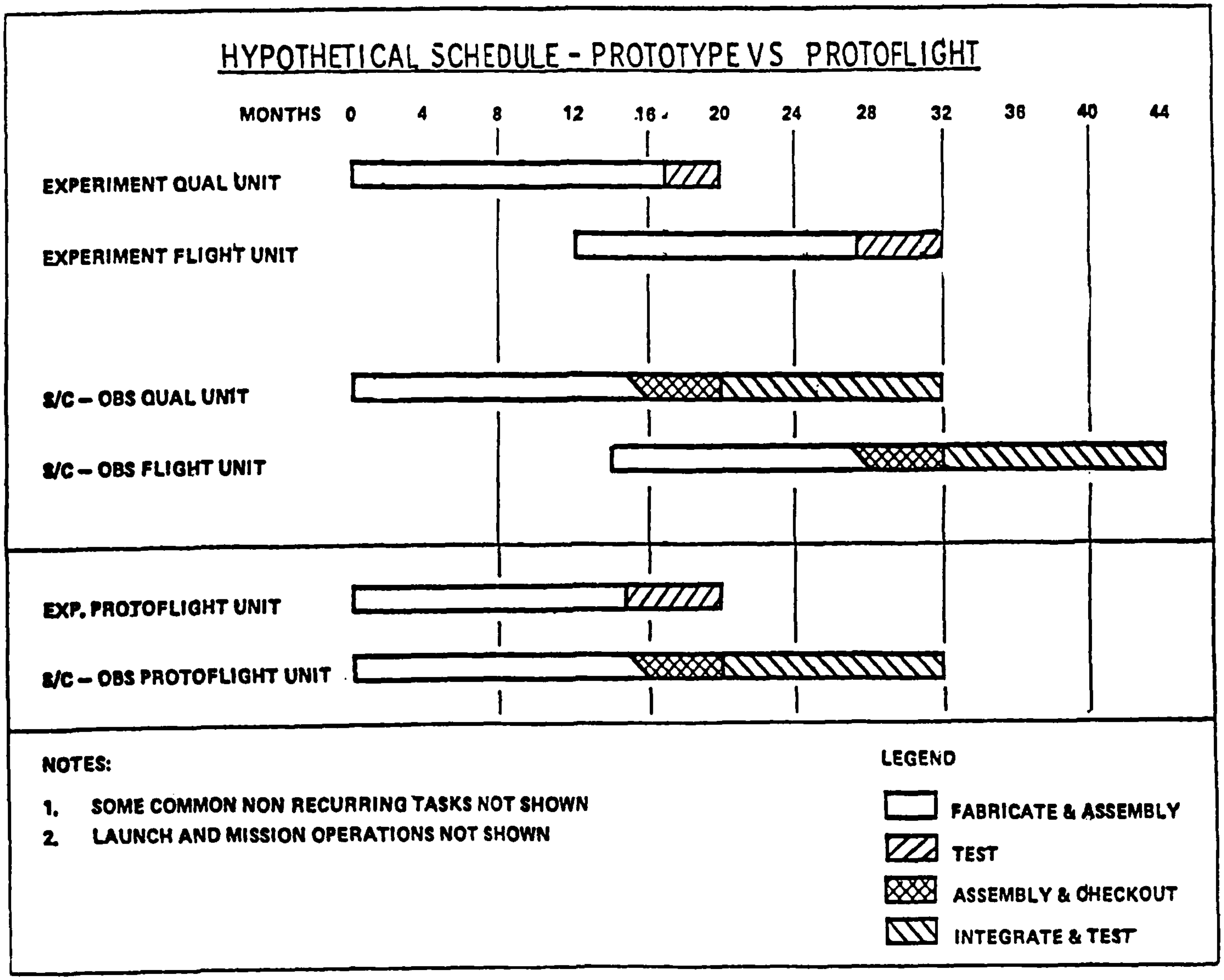


FIGURE 3 SAMPLE MANUFACTURING & TEST SCHEDULE

VOYAGER IMAGING SYSTEM

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Abstract

The Voyager spacecraft imaging instrument has been a system development by JPL, conducted from 1972 through 1976 to support scientific explorations at Jupiter, Saturn and Uranus. Its images of the Jovian satellites and Jupiter itself have been shown in three-color illustrations throughout the world during 1979.

Mission reliance on this instrument to function reliably on two spacecraft at hundreds of millions of miles from Earth and years after launch placed stringent demands on the reliability aspects of the instrument development. Detailed technical knowledge and understanding of every aspect of imaging instrument function and performance were sought to defend against risks in the Voyager missions.

Introduction

In 1973 NASA and Congress authorized the Voyager mission to Jupiter and Saturn. This mission was planned with two spacecraft, each carrying both a long and a short focal length television system. These systems were required to perform reliably over a mission lifetime of ten years, with one of the spacecraft targeted to the planet Uranus, for a total mission flight time of two years.

Experiment Description

The Voyager imaging science subsystem consists of two cameras, a wide angle camera and a narrow angle camera. Each camera consists of an optics subassembly that includes an eight-position filter wheel with position identification sensors, a focal plane shutter assembly that includes light flood lamps, a camera head that includes a magnetically focused and deflected slow scan vidicon for the conversion of optical images to electronically processible data, a support electronics subassembly, and a power supply subassembly.

The wide angle camera has a 200 mm focal length lens operating at a fixed relative aperture of f/3.5 and a field of view of 56 x 56 µrad. The narrow angle camera contains a catadioptric telescope with a 1500 mm focal length lens operating at a fixed relative aperture of f/8.5 and a field of view of 7.4 x 7.4 µrad. The timing and control functions are contained in the spacecraft flight computer and are brought to the cameras by a set of 18 interface lines for each camera. In addition, a set of 5 interface circuits present the digital video, filter position, analog engineering telemetry and temperature sensors on board to the computer for processing and formatting.

The video data consists of 800 pixels per line and 800 lines per frame. Each pixel is encoded to 8 bits to provide 256 shades of gray. Therefore, there are 5,120,000 bits per picture which are converted at a rate of 172.8 kbps and are transmitted at a rate of 115.2 kbps. It requires 48 seconds to read out a picture of the picture transmitted rate. Each camera has several modes of operation: normal exposure mode, which shutters the cameras at one of the available exposure times from 5 µs to 15.3 s; a long exposure mode which provides exposures in multiples of 48 seconds; a simultaneous exposure mode whereby each camera is shuttered at the same time; and an automatic exposure mode whereby the exposure is determined by the content of the previous exposure, corrected for the filter that was used and the desired filter for the picture which is to be taken.

In addition to these exposure modes, there are 5 read out modes: 1:1, 2:1, 3:1, 5:1, and 10:1. In these modes the picture is stored on the vidicon and read out at the lower data rates indicated by the above ratios. There are also two basic edit modes whereby a partial picture can be read out at full resolution containing either 3/4 or 1/3 of full frame, or a full frame containing either 1/5 or 1/10 of the total pixels. Both of the above slow scan and the edit modes are incorporated to accommodate reduced telemetry capabilities while providing real time pictures.

System Design Constraints

The design constraints for the Voyager television system may be divided into three basic areas: 1) science requirement constraints, 2) mission constraints, and 3) spacecraft constraints.

The science requirements constraints dictate primarily the performance parameters such as focal length, focal ratio, MTF and spectral range, noise performance, digital resolution, optical filters, shutter speed, etc.

The mission constraints impact the design in the area of lifetime requirements and environmental requirements. For the Voyager mission these were the roughest requirements to meet. The operational lifetime requirement was for ten years unattended. The radiation environment at Jupiter placed the most severe requirements on the selection of parts and material. It was required that the imaging system operate after receiving a total dose of 60 K Rads and operate with little or no interference while receiving a fluence of 2.5×10^{12} electrons per cm^2. The spacecraft constraints imposed weight limits, power limits, vibration levels, magnetic levels, EMI and EMC levels, and an environmentally related requirement for an equal-potential spacecraft.

The Design Process

At the onset of the program all of the known constraints (though sometimes not yet quantified) were considered and a system was defined around as many known and proven elements as possible. For example, the N. A. optics was the same design of the optics used on Mariner Venus Mercury. The shutter and filter wheel mechanisms were third or fourth generation mechanisms which had a proven lifetime and reliability. JPL was in the throes of an extensive electronic parts characterization for radiation damage. A few selected I.C.'s were also undergoing a radiation hardening development. This provided a very restrictive list of electronic components from which to design the required circuits. Having gone through this process, components or elements were identified which had known problems or some unknown aspect, and extensive test and qualification programs were initiated where adequate substitutes could not be found. For example, the vidicon itself proved to be the weakest link for lifetime in the system. A program was initiated to develop a new filament and cathode which would provide for the required lifetime. Further, a circuit was added to the system to allow small changes to the grid voltage of the vidicon which, due to the electron optics of the tube, would allow a new spot on the cathode to be used when the cathode current degraded. Tests also had to be devised to characterize the radiation interference performance of the vidicon, the signal chain, and the optical elements of the system.

The next step was to compile a comprehensive set of derating guidelines for all components to be used in the system. This included stress limits, part tolerance, aging effects, tolerance on the rated value, thermal derating and radiation derating. Radiation derating was continuously updated as the design process progressed. This was due to primarily two factors: 1) many components were not yet characterized at the time the design was initiated, and 2) Pioneer flew by Jupiter which impacted the radiation model being used. The next step in the process was to set design priorities for tradeoff criteria. The set selected were: design problems would be solved first by circuit design on component selection, or in the case of mechanical or optical design by material selection; second, in the case of radiation or thermal problems by location within the subsystem; and third, by external shielding or spot shielding for radiation effects.

It was the careful attention to these concepts and design criteria that defined the final system. For example, the timing and control function resided in the spacecraft Flight Data System (FDS) primarily because the FDS was a redundant system, whereas the television was not. The W. A. optics, which was a totally new design, was designed around radiation hard glass. One other very stringent rule that was applied was that no design change was allowed to take place without first investigating the entire system for hidden impacts.

Keys to Reliability and Performance Assurance

Many specific items were combined to

provide reliability and performance assurance. For discussion purposes, three phases of hardware activity will be considered: the conceptual design phase, the detailed design phase, and the design verification and qualification phase.

The key element of the conceptual design phase is the configuration of the instrument. In determining the configuration, the following issues were addressed:

.Instrument functional split with spacecraft

.Spacecraft interfaces

.Instrument independency

.Instrument redundancy

Each of these items were examined early in the program to insure a rational, reliable, and testable instrument configuration. Often times, these issues came head to head with existing spacecraft constraints and/or monetary constraints. Compromises were then made on both sides. For example, full instrument redundancy would provide the greatest assurance for success, but was ruled out on individual spacecraft after consideration of the dual spacecraft launch. Instead, the wide angle and narrow angle cameras were made independent of each other. The functional split between the television system and the spacecraft flight data system (FDS) was also made at this phase of the design, with the logic control functions coming from the FDS and the digital data flowing to the FDS.

The next design phase was the detailed design. Considered during this activity were:

.Circuit design constraints

.Mechanical design constraints

.Optical design constraints

.Proven approaches

.Qualified parts selection lists

.Failure modes and effects criticality analysis

.Worst case analysis

.Configuration control

.Design reviews

These items were all key elements and were all used to both control and influence the design activity. A detailed design constraints document was generated at the beginning of the detailed design phase to control and influence the overall design. Past approaches proven effective were incorporated wherever possible and past concepts relied upon for the new design work. Space and radiation qualified parts were compiled into lists and parts selected for design purposes came, where possible, from these lists. Where parts could not be selected from an approved list, qualification of the selected parts took place. A failure modes and effects analysis was performed on all circuit and instrument intakes, and the design was changed where appropriate. This analysis was particularly important as instrument interfaces. Worst case analysis was performed on all circuit designs to a Voyager project approved set of component tolerance variations. This set of analyses was especially important for the Voyager television system as it provided the only inclusive way to determine performance of the instrument under radiation. Configuration control and design reviews were used throughout the design phase to both keep track of the design and control its evolution and to insure that, in the case of the design reviews, to provide an overview activity, provide additional, impartial expertise, and other constructive guidance. All of these items were important in the reliable and understood design and expected operation of the imaging instrument.

Following the detailed design activity, the design verification and qualification phase was undertaken. This phase was an extremely important one, as it empirically verifies or refutes the design assumptions made during the detailed design phase. Included in this effort were parts qualifications, subsystem testing, instrument qualification, and system testing.

Some of the items considered during this phase were:

.Parts qualification

.Vidicon qualification

- .Circuit testing
- .Subsystem testing
- .Instrument qualification
- .Design reviews
- .Problem and failure reports
- .Configuration management
- .System testing

All of these items were of importance and contributed greatly to the success of the overall effort. In support of this, a hardware compliment that consisted of developmental assemblies, a breadboard, prototype for design qualification, flight spare, and flight units was utilized. Parts qualification was vital; many of the components used did not initially have radiation performance history. This information was vital to confirm the design margins used in the design and analysis. The testing, both circuit and subsystem, provided both performance data and verification of key parts of the analysis. In addition, many key things such as noise performance, not readily amenable to exact analysis, were checked. Testing at this level was also performed over temperature and voltage extremes, and selected subassemblies experienced radiation, vibration, and thermal vacuum testing.

The subassemblies then were combined and went into a flight environmental margin and performance test sequence to verify the complete instrument performance.

From this point, integration and testing on the spacecraft was used to validate the spacecraft/television interface and the interface design assumptions used. Supporting these efforts were design reviews at initial points (preliminary, detailed, and pre-shipment formal reviews were held, along with a series of informal design reviews), configuration management of the design requirements and drawings, a problem failure and reporting system, and weekly project meetings.

Approach Considerations

The design approach used on the Voyager mission for the television system is essentially the same as that used on previous JPL spacecraft in the Mariner and Surveyor and Viking series. This approach has been found to be very effective in terms of identifying design problems and in terms of verifying analytically design margins for the hardware use. In the case of the Voyager activity, four years were expended in going through first the subsystem requirements generation, the detailed design of the instrument, the analysis to support the design, and then the testing to verify that the analysis and the design practices themselves were sound. This approach has been very productive and all phases of the approach outlined have identified and eliminated potential failure and performance limitation mechanisms in the design. A disadvantage to this approach is the length of time required to go through these processes and the expense involved, particularly in doing a sophisticated worst case analysis and a detailed test program with the hardware. In the case of the Voyager mission, these were vital keys to the overall reliability obtained with an instrument that was not redundant on the spacecraft launch of long duration. Without the confidence generated by these approaches, certainly the requirements of a long lifetime deep space mission could not be adequately met.

Conclusions

This paper describes in some detail the design process undertaken for the Voyager imaging system on the current Voyager spacecraft mission to the planets Jupiter, Saturn and Uranus. This approach follows a systematic design, development and testing activity aimed at eliminating design and manufacturing defects and verifying, to the extent possible, performance anticipated at the spacecraft encounters. Although fairly expensive in terms of time, effort, and money, this approach has proven effective in assuring reliability under long duration, environmentally difficult conditions.

Acknowledgement

This paper represents the results of the Voyager Imaging Science Subsystem development conducted by the Jet Propulsion Laboratory, California Institute of Technology, under NASA contract NAS7-100.

SCIENCE OBJECTIVES OF MJS
IMAGING SCIENCE INVESTIGATION

OBTAIN GLOBAL COLOR PHOTOGRAPHY OF JUPITER AND SATURN, AT BETTER THAN EARTH-BASED RESOLUTION, OVER AN EXTENDED PERIOD.

MEASURE THE MOTIONS OF SMALL CLOUD FEATURES TO RELATE LOCAL WIND CHARACTERISTICS TO GLOBAL DYNAMICS.

OBSERVE VERTICAL STRATIFICATION IN THE ATMOSPHERES OF JUPITER, SATURN, TITAN AND OTHER BODIES WITH SUBSTANTIAL ATMOSPHERES.

ACCURATELY CHARACTERIZE THE OPTICAL PROPERTIES OF THE PLANETS AND MAJOR SATELLITES, OVER A WIDE SPECTRAL RANGE, AFTER A FOUR-YEAR FLIGHT.

INVESTIGATE COLOR VARIATIONS IN THE PLANETARY ATMOSPHERES AND ON THE SATELLITE SURFACES.

OBTAIN HIGH RESOLUTION (1 km), LOW SMEAR IMAGES OF SEVERAL SATELLITES TO CHARACTERIZE SURFACE GEOLOGIC STRUCTURE.

MEASURE THE FIGURE AND SPIN AXIS ORIENTATION OF THE MAJOR SATELLITES.

DETERMINE THE SPATIAL DISTRIBUTION OF METHANE AND ATOMIC SODIUM ON THE PLANETS AND IO, RESPECTIVELY.

OBTAIN HIGH RESOLUTION (1 km), LOW SMEAR IMAGES OF THE RINGS OF SATURN.

OBSERVE THE DARK SIDE OF JUPITER TO SEARCH FOR LIGHTNING, AURORAE, OR METEORS.

MINIMIZE COVERAGE LOSSES DUE TO POINTING ERRORS.

MAXIMIZE THE EFFICIENCY OF IMAGING DATA RETURN AT SEVERAL DATA RATES.

VOYAGER IMAGING SYSTEM

MAJOR DESIGN PHASES

MISSION DEFINITION

CONCEPTUAL DESIGN PHASE

KEY ELEMENTS

- INSTRUMENT FUNCTIONAL SPLIT
- SPACECRAFT INTERFACES
- INSTRUMENT INDEPENDENCY
- INSTRUMENT REDUNDANCY

DETAILED DESIGN PHASE

KEY ELEMENTS

- CIRCUIT DESIGN CONSTRAINTS
- MECHANICAL DESIGN CONSTRAINTS
- OPTICAL DESIGN CONSTRAINTS
- PROVEN APPROACHES
- QUALIFIED PARTS SELECTION LISTS
- FAILURE MODES AND EFFECTS CRITICALITY ANALYSIS
- WORST CASE ANALYSIS
- CONFIGURATION CONTROL
- DESIGN REVIEWS

VERIFICATION AND QUALIFICATION PHASE

KEY ELEMENTS

- PARTS QUALIFICATION
- VIDICON QUALIFICATION
- CIRCUIT TESTING
- SUBSYSTEM TESTING
- INSTRUMENT QUALIFICATION
- DESIGN REVIEWS
- PROBLEM AND FAILURE REPORTS
- CONFIGURATION MANAGEMENT
- SYSTEM TESTING

VOYAGER IMAGING SYSTEM

Circuit Margin Testing

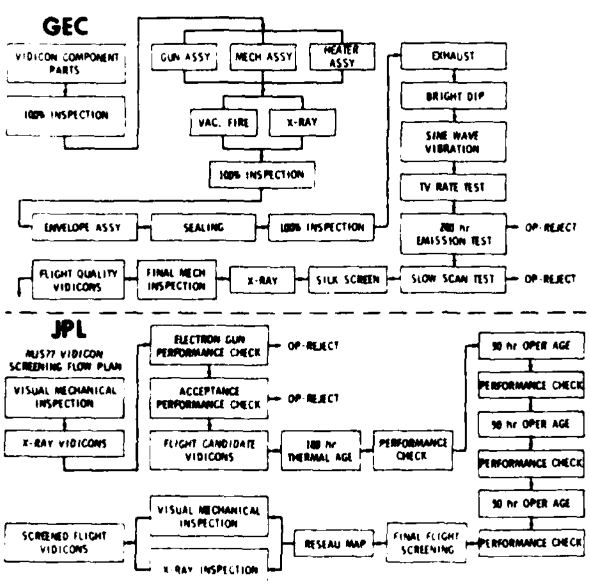
1. Circuits to be margin tested over worst case combinations of:
   - a) DC Voltage:

+ 15v	±10%
- 15v	±10%
+ 4v	±10%
+ 40v	± 5%
+ 50v	±10%
-100v	± 5%

     Power supply tested with input power:

     2400 Hz ±10%, 100v P-P ±10%
   - b) Temperature:

Bus Electronics	-30°C to +85°C
Camera Assemblies	-30°C to +45°C
Camera Circuits	-30°C to +70°C
   - c) Source/load impedance levels
   - d) Input Waveform Tolerances
2. Parameters Measured and Recorded
   - a) Critical output parameters
   - b) Power dissipation
   - c) Phase Margin
   - d) Internal bias levels
   - e) Internal logic levels
   - f) Survival and Recovery time under output short circuit and input over voltage conditions where applicable.



MJS F.W. AND SHUTTER MECHANISMS

TEST PROGRAM

MOLESINK -- ENGINEERING MODELS ONLY (F.W. & SHUTTERS)
FASTEX MOVIES -- ENGINEERING MODELS ONLY (F.W. & SHUTTERS)

ENVIRONMENTAL (F.W. & SHUTTERS)
- VIBRATION TO T.A. LEVELS -- ENGINEER UNITS
- THERMAL TO F.A. LEVELS -- ALL UNITS

LIFE TEST - CONTINUOUS CYCLES (F.W. & SHUTTERS)
- ENGINEERING MODELS -- 50,000 CYCLES

ASSEMBLY SCREENING (F.W. & SHUTTERS)
- PROTOTYPE MODELS -- 20,000 CYCLES
- FLIGHT UNITS -- 1,000 CYCLES

OPERATING CHARACTERISTICS AND CALIBRATION (ALL SHUTTERS)
- MEASURE AND RECORD
  - LIGHT LEAK
  - ▲ BLADE BOUNCE
  - ▲ EXPOSURE - ACTUAL TIME vs. COMMAND TIME
  - ▲ BLADE SPEED AND REPEATABILITY (TRAVEL TIME, DELAY, AND ACCELERATIONS)
  - ▲ SHADING
  - ▲ MARGIN TESTS (MINIMUM VOLTAGE, CAPACITANCE, AND PULSE WIDTH)

FILTER WHEEL (ALL UNITS)
- BACKLASH
- VERIFY I.D. POSITION CODING
- MARGIN TESTS

▲ TESTS REPEATED IN INCREMENTS THROUGH F.A. TEMPERATURE RANGE.

WIDE-ANGLE LENS BARREL DESIGN CONSTRAINTS

DESIGN ENVELOPE	12-in. LONG BY 8-in. SQUARE	
WEIGHT	2.5 lbs	
MINIMUM BACK FOCUS	3.2 in.	
DEPTH OF FOCUS	±0.001 in.	
OPERATING TEMPERATURE RANGE	-20° TO +40°C	
TA VIBRATION LEVELS	SINUSOIDAL VIBRATION LEVELS	
	5 TO 12 Hz	1.02 cm DOUBLE AMPLITUDE
	12 TO 30 Hz	2.0 G rms
	30 TO 100 Hz	8.0
	100 TO 2000 Hz	4.5
	RANDOM VIBRATION	11.1 G rms OVERALL
RADIATION ENVIRONMENT	1×10^{13} electrons/cm^2 3 MeV electrons	
MAGNETIC MATERIALS	LIMIT USE OF MAGNETIC MATERIALS	

WIDE-ANGLE LENS BARREL PROBLEM AREAS

RADIATION ENVIRONMENT — SEVERE RADIATION ENVIRONMENT LIMITS USE OF PREVIOUSLY FLIGHT-QUALIFIED ORGANIC MATERIALS

MATERIALS IN QUESTION

1. DUROID
2. RULON A
3. TEFLON
4. DRY LUBRICANT (ELECTROFILM)
5. CAT-A-LAC-FLAT BLACK PAINT
6. CHEMGLAZE F306 FLAT BLACK PAINT AND PRIMER
7. VITON
8. OPTICAL MATERIALS

MJS WIDE-ANGLE LENS DEVELOPMENTAL TESTS

A. OPTICAL PERFORMANCE TESTS
   1. SYSTEM WAVEFRONT
   2. LIMITING RESOLUTION
   3. FOCAL LENGTH
   4. BACK FOCAL LENGTH
   5. OPTICAL AXIS ALIGNMENT
   6. T-STOP
   7. VIELING GLARE

B. VIBRATION AND ACOUSTIC TESTS (COMPLETE WIDE-ANGLE CAMERA)
   1. LOW LEVEL SINE SWEEPS
   2. FA LEVEL SINE AND RANDOM VIBRATION
   3. TA LEVEL SINE AND RANDOM VIBRATION
   4. ACOUSTIC

C. THERMAL - VACUUM
   1. THERMAL FOCUS SHIFT MEASUREMENT
   2. VACUUM/AIR FOCUS SHIFT MEASUREMENT
   3. TA THERMAL CYCLE TEST

TA TEST SEQUENCE (PROTOTYPE)

- ACCEPTANCE TEST
- BENCH CALIBRATION
- RADIATION
- SYSTEM VERIFICATION
- MECHANICAL TEST
- SYSTEM VERIFICATION
- THERMAL VACUUM AND CALIBRATION
- SYSTEM VERIFICATION
- EMI / EMC
- MAGNETIC

FA TEST SEQUENCE AND CALIBRATION (FLIGHTS 1, 2, AND 3)

- COMPONENT LEVEL PRIOR TO INTEGRATION OF OPTICS
  - OPTICS
  - FILTERS
  - SHUTTERS
  - VIDICONS
- ACCEPTANCE TESTS
- BENCH CALIBRATION #1
- MECHANICAL TEST
- SYSTEM VERIFICATION
- THERMAL VAC + 2 CALIBRATION
- SUBSYSTEM VERIFICATION
- BENCH CALIBRATION #2
- EMC / EMI IF REQUIRED
- MAGNETIC IF REQUIRED
- SYSTEM VERIFICATION (SAF)
- BENCH CALIBRATION #3 (PRIOR TO DELIVERY TO ETR)
- SYSTEM VERIFICATION (ETR)

COST EFFECTIVE PARTS SELECTION CRITERIA

Leland D. Swanson

RELIABILITY ENGINEER, TRW/DSSG

For most hardware system design and development programs, the requirements for the selection of parts is established during the proposal phase when very little information is available. For a cost effective mission assurance program, it is essential that the selection of parts be compatible with the system reliability requirements, however, the total cost of the mission must also be minimized.

In this presentation, I will discuss a parts cost trade-off study made to verify the part selection criteria for the MX Missile Instrumentation and Flight Safety System (IFSS). The IFSS is not important to my purpose in this presentation. It merely provides the vehicle to illustrate some techniques which can be used early in a design and development program to guide management in making cost effective decisions relative to part selection criteria and mission assurance.

The Instrumentation and Flight Safety System for the MX missile monitors missile performance during flight test. It consists of airborne instrumentation (ABI) which senses, conditions, and transmits data on missile performance, and ground based support equipment (SE) to receive and process the test flight data. The ABI also contains a command-destruct Flight Safety Subsystem to destroy the missile should it become necessary. This presentation is concerned only with the ABI portion of the IFSS.

Physically, IFSS/ABI components are located in all stages of the missile with the main elements located in Stage IV and the Reentry System. IFSS/ABI components include items such as multiplexers, power supplies, signal conditioners, a receiver/decoder, transponders, batteries, various signal processors and sensors, amplifiers, transmitters, antennas and of course the interconnecting cabling.

During this presentation, we will very briefly review the results of a parts cost versus reliability trade study for the IFSS/ABI and cover the topics shown on Slide 1. The purpose of the study was to resolve a recurring management question as to the appropriateness of the part selection criteria imposed on the IFSS/ABI.

The IFSS/ABI reliability requirements are summarized on Slide 2. The Telemetry G&C Data Link and the Flight Safety Subsystem (FSS) flight termination function are considered critical for safety reasons, therefore, the prelaunch and flight reliability requirements for these functions are specified separately.

For the purpose of our study, we divided the alternatives for part selection into four categories as shown on Slide 3. The part selection criteria is based on SAMSO-STD-77-7 which is the control document for standardizing parts, materials and processes for the MX missile. The AVE/OSE category of parts consists of parts procured to the best available specifications which include special provisions for process baseline controls, parameter drift screens, and destructive physical analyses. The ABI category of parts is composed of high and medium grade military spec parts. The TSE/MSE category is composed of lower grade mil-spec parts while the category on the right consists of parts procured to nothing more than suppliers part numbers or commercial catalog information.

The assumptions and conditions used to establish the relationships between parts cost and failure rates are shown in Slide 4. To establish the parts cost, prices were obtained from a number of sources using a base quantity of 1,000. Failure rate information was obtained from actual experience on the MINUTEMAN program and from MIL-HDBK-217.

The results of the parts cost vs. failure rates portion of the study is shown on Slide 5. It is interesting to note that for electronic parts, two orders of magnitude improvement in reliability can be obtained for a relatively small increase in parts cost. The relationships between parts cost and failure rates shown in Figure I forms the basis for

expanding the cost trade-off study to the IFSS/ABI component and system level.

The assumptions and conditions used to expand the parts cost vs. failure rate study to the IFSS Master Multiplexer Unit (MUX) are shown in Slide 6. The MUX electronic parts cost and probability of failure are derived from the parts cost and failure rate information of Figure I, multiplied by the MUX parts count.

The results of the parts cost vs. reliability trade study on the MUX is shown in Slide 7. The MUX risk cost was calculated by multiplying the estimated cost of the MUX by its probability of failure. The composite cost curve is simply the sum of the electronic parts cost and the MUX risk cost. Figure II indicates that if one considered the MUX alone for prelaunch operation, the optimum choice of parts from a cost standpoint would be the TSE/MSE category of parts, i.e., lower grade military spec parts. It also illustrates that the use of commercial parts would not be cost effective.

However, to determine the optimum selection of parts for the MUX in prelaunch operation is not our objective. Our objective is to determine the optimum parts selection criteria for the entire IFSS/ABI system considering both prelaunch operation and the flight phase of the missile flight test. To accomplish this objective, the additional assumptions shown in Slide 8 were made. The mission recycle cost is defined as the cost of interrupting a flight test because of an IFSS/ABI failure, finding and repairing the cause, and recycling the flight test sequence. In the worst case, this would include cancelling and rescheduling the test flight.

The results of expanding the parts cost vs. reliability trade study to the IFSS/ABI System level considering prelaunch operations only, is shown in Slide 9. These results were derived in a manner similar to that used for the MUX described previously. Three different curves are shown which represent the risk cost associated with the lower, medium and higher estimated mission recycle cost.

Slide 10 shows the same information presented as composite costs, i.e., the parts cost and the mission recycle risk costs are summed. The composite cost curve permits one to establish the minimum cost point and to determine the optimum parts selection category. Using the lowest estimate for mission recycle cost, the location of the minimum cost point indicates that the selection of TSE/MSE parts would be appropriate for prelaunch checkout operation of the IFSS/ABI. For the medium and higher estimate of mission recycle costs, the selection of ABI category of parts would be more appropriate.

The results of the parts cost vs. reliability study on IFSS/ABI for the flight phase of the mission is shown in Slide 11. The assumption has been made that an IFSS/ABI failure could result in a loss of the mission ranging from 5% to 100%, i.e., a IFSS/ABI part failure could result in only a small loss of data or a complete loss of the mission depending upon where the failure occurred in the system and the time during the flight at which it occurred.

Slide 12 shows the now familiar composite curve of parts cost and mission risk cost as a function of IFSS/ABI probability of failure for the flight portion of the mission considering a 5%, 20% and 50% loss of the mission data. It also shows the minimum cost and optimum selection of part quality assurance levels considering only the flight portion of the mission.

To complete the parts cost vs. probability of failure study for the entire mission, the study results from the prelaunch and flight portions of the mission must be combined. This combination is illustrated in the next three slides as Figures VII, VIII and IX.

Figure VII shows the results of the study considering the entire mission using the most conservative assumptions, i.e., the lowest estimates for missile recycle cost and loss of flight data as a consequence of a IFSS/ABI part failure. Under these assumptions, Figure VII indicates that the optimum selection of parts for the IFSS/ABI would be the TSE/MSE category of parts, i.e., lower grade mil-spec parts.

Figure VIII shows the results of the study for the entire mission using a medium estimate for missile recycle cost ($700K) and a 20% mission loss of flight test data. Figure VIII indicates that using a mix of the higher and lower grade mil-spec parts would be the most cost effective under these assumptions.

Figure IX illustrates the result of the study using the higher estimate of missile recycle cost ($2M) and a 50% mission loss of test flight data. The figure indicates that the optimum part selection criteria under these assumptions would be ABI parts, i.e., higher grade mil-spec parts.

The question now arises as to what level of parts are required for the IFSS/ABI system to meet the reliability requirements as identified on Slide 2.

The matrix on Slide 16 shows the results of reliability predictions based on the failure rates for the ABI category of parts as determined from MIL-HDBK-217C.

The predictions indicate that all of the IFSS/ABI reliability requirements will be met using parts selected from the ABI category.

The matrix on Slide 16A shows the results of a similar prediction using the failure rates for the TSE/MSE category of parts. The prediction clearly indicates that the IFSS/ABI system will not meet the reliability requirements with parts selected from the TSE/MSE category of parts.

Conclusions and recommendations from the study are summarized on Slide 17 and 18 respectively. The study confirmed that the parts selection criteria specified for the IFSS/ABI was optimum from a cost standpoint and satisfies the system reliability requirements.

TESTING APPROACH FOR MX MISSILE INERTIAL MEASUREMENT UNIT

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The purpose of this presentation is to show how the test methods and test equipment for the MX Missile Inertial Measurement Unit (IMU) are being determined. There are five parts to the presentation. The first two parts are a description of the IMU. The third part discusses the methodology being used to develop the test methods and test equipment. The fourth part covers the status of test methods and test equipment at the completion of the Advance Development Program (ADP) and the start of the Full Scale Engineering Development (FSED) program. The fifth part is an audio-slide presentation showing the projected maintenance operations.

PART 1. ELECTRICAL DESCRIPTION OF THE MX IMU

The MX IMU consists of an all-attitude, radiation hardened, floated, stable platform that supplies the MX Guidance Computer with velocity and attitude information. It is a continuation of the Missile Performance Measurement System developed under Air Force Contract by the Charles Stark Draper Laboratory. The program is in its fifth year and four ADP IMUs have been built and delivered to the Air Force. These IMUs are undergoing evaluation and characterization tests.

Figure 1. IMU Electronics Block Diagram

This figure shows the interrelations of the functions necessary to mechanize the IMU.

The dashed lines represent major physical partitioning of the IMU. To the left of the first dashed line is the outside world. Between the two dashed lines is the external electronics, and to the right of the second dashed line is the floated stable platform - (i.e., stable member). The stable member is floated in a fluorocarbon fluid - FC-77.

POWER FUNCTION

- IMU POWER

  The outside world source of +76 VDC operating power.

- HI VOLT REG

  Contains the EMI filters and supplies regulated +68 VDC to the IMU.

- DC/DC CONV ±15/REG

  Converts the regulated +68 VDC to secondary operating voltages for the external electronics.

- MUXR FILTER

  Modulates/Demodulates data on the +68 VDC power line for transmission to/from the stable member. The only physical connection to the stable member is via the power brushes.

- FILTER DC/DC CONV ±15V REG

  Converts the +68 VDC to secondary operating voltages for the stable member.

TIMING FUNCTION

Generates the precision frequencies and timing signals for the IMU.

- HARD TIMER

  Contains the Xtal oscillator, countdown chain, retention flip-flops. Supplies the precision frequencies.

- COMM

  Generates timing signals in response to outside mode commands.

- TGII EXCIT

  Supplies wheel power, pick-off excitation, and suspension power to the Third Generation Inertial Instruments (TGII) and thrust valves.

STABILITY FUNCTION

Maintains the stable member oriented in inertial space. This creates the stable platform.

- TGG

  The single degree of freedom Third Generation Gyros (TGG) supply the inertial reference.

- TURBOPUMP

  The turbopump supplies FC-77 under pressure. The FC-77 flow is controlled by the thrust valves to rotate the stable member.

- STAB/VALVE ELECT

  The outputs from the TGG is processed to generate control signals to thrust valves.

- TORQ GEN DRIVE

  Under control of the outside computer, it generates TGG torquing signals. These signals are used for test and calibration.

VELOCITY FUNCTION

Measures velocity along three orthogonal axis.

- SFIR

  Specific Force Integrating Resolver (SFIR) is a precision integrating accelerometer. Its resolver output is a whole angle representing velocity.

- VELOCITY READOUT

  Converts the SFIR outputs to digital words for transmission to the outside world.

ATTITUDE FUNCTION

Determines the attitude of the stable member with respect to the outside world.

- ATTITUDE EXCITATION

  Supplies the signals that excite the driver bands. Three driver bands are mounted orthogonally on the surface of the stable member.

- ATT BANDS

  The three driver bands induce a signal in the receiver band. The receiver band is mounted on the equatorial ring which is fixed to the missile structure.

  The driver band signals are magnetically coupled to the receiver band across the FC-77 flotation fluid.

- ATTITUDE READOUT PROCESSOR

  Converts the receiver band signal to a digital word for transmission to the outside world.

COMMUNICATIONS FUNCTION

Performs the communications between the outside world and the IMU.

- COMM (right of second dashed line)

  Formats outgoing data from the stable member. The data consists of digital words, pulse-position modulated analog data, delta modulated temperature data, and discrete pulses. It generates the error detecting codes associated with the outgoing data.

  It decodes the incoming commands, checks for transmission errors, and issues the commands to the affected function.

- MUXR FILTER

  Modulates/demodulates the data from the power line.

- COMM (between the dashed lines)

  Receives data from the stable member, checks for transmission errors, reformats the data, and transmits it to the guidance computer. It receives commands from the guidance computer, checks for transmission errors, reformats the commands, adds the error detecting codes, and transmits the commands to the stable member.

TEMPERATURE CONTROL FUNCTION

Controls the temperature of the FC-77 flotation fluid.

- CIRCULATOR PUMP

  The IMU is cooled by expanding liquid freon in a heat exchanger. The FC-77 flotation fluid is pumped across the heat exchanger by the circulator pump. The speed of the circulator pump is controlled by closing a loop through

the computer. The temperature of the flotation fluid is sensed at the turbopump and transmitted to the computer. The computer uses this temperature value to compute the required speed of the circulator pump.

SUSPENSION FUNCTION

The suspension function maintains the stable member centered in the flotation chamber.

- SUSPENSION PADS

  The stable member is neutrally buoyant at a single temperature of the FC-77 flotation fluid. The stable member is centered in the flotation chamber by pumping FC-77 through the eight suspension pads.

PART 2. PHYSICAL DESCRIPTION OF THE IMU

The unique mechanical, thermal, and packaging design of the MX IMU is shown by a series of 15 photographs showing an IMU being disassembled.

Figure 2. MX IMU (ADP Model)

The IMU ready for installation into the guidance and control drawer.

The photo shows:

- Freon input/output ports
- Electrical Connectors
- Support Ring

Figure 3. Exploded View of the IMU Mock-Up

- Upper cover
- External electronics
- Upper heat exchanger and power shell
- Stable member
- Equatorial ring
- Lower power shell

Figure 4. Exploded View Showing Additional Details

Starting from the far left:

- Cavity cover
- SFIR electronics w/micro circuit hybrids
- SFIR

Starting from the right:

- cavity cover
- TGG electronics w/hybrids
- TGG
- Power conditioner
- Turbopump electronics
- Turbopump
- Attitude driver bands
- Attitude receiver band

Figure 5. Top Cover Removed

The photo shows:

- The external electronics

Figure 6. Lower Cover Removed

The photo shows:

- The lower heat exchanger
- Volume compensators
- Circulator pump

Figure 7. Support Ring Removed

The photo shows:

- Sphere assembly
- Circulator pump
- Freon pressure regulators
- Power and multiplexer line

Figure 8. Upper Heat Exchanger Removed

The photo shows:

- Power and multiplexer connector
- Upper power shell
- Heat exchanger/flotation interface
- Isolation mounts
- Equatorial ring with fluid passages
- Support ring

Figure 9. Upper Shell Removed

The photo shows:

- The stable member in the flotation chamber

Figure 10. The Stable Member Removed From the Flotation Chamber

The photo shows:

- Stable member
- Attitude bands and drive electronics
- Thrust valves
- Suspension pads
- Power/muxr brushes
- Balance screws
- Cavity covers

Figure 11. Removing Cavity Cover

The photo shows:

- The cavity cover being removed
- The attitude driver bands removed

Figure 12. TGG Cover Removed

The photo shows:

- The TGG mounted in the cavity

Figure 13. The TGG Removed

The photo shows:

- The power conditioner Circuit Board Assembly (CBA) with hybrids

Figure 14. Power Conditioner CBA Removed

The photo shows:

- Turbopump electronics hybrids

Figure 15. SFIR Cavity and Cover

The photo shows:

- The four SFIR CBA's
- SFIR

Figure 16. The Stable Member

The photo shows the stable member floating in the buoyancy and balance tank.

PART 3. METHODOLOGY BEING USED TO DEVELOP THE MX IMU TEST METHODS AND TEST EQUIPMENT

Figure 17. MX IMU Test Objectives

The first step in developing a test approach is to define the test objectives.

- The tests must verify that the product meets the performance requirements.

- Factory and maintenance requirements are similar, but not identical. When these differences are not addressed and resolved during the development phase of a program, the product design will be optimized for factory build. This results, at best, in a set of tests, test equipment, test methods, test procedures, etc. for the factory and a whole new set for maintenance. At worst, it results in a product that can be built and delivered but not maintained. Thus, these differences become major drivers in the life cycle cost.

Figure 18. Performance Requirements

These are the performance requirements that testing can verify and have a major effect on the test approach.

- System accuracy determines the test equipment accuracy.

- Reliability affects factory test methods. For example, burn-in, parameter drift screening, thermal cycle, etc.

- Interchangeability - affects test methods - test in next assembly, parametric tests, hot mock-up etc.

Figure 19. Factory Requirements

These are the major factory requirements that the test approach must satisfy:

- System accuracy must be verified before the IMU can be delivered.

- Special tests must be performed to verify reliability. Maintenance does not perform reliability tests, operational reliability is verified by maintaining failure records.

- Faults must be identified before a large investment is made in the item.

- Interchangeability requires that the tests be comprehensive enough to insure that the item will function with the other elements when the tolerances all go the wrong way.

Figure 20. Maintenance Requirements

These are the major maintenance requirements that the test approach must satisfy:

- The system accuracy requirement is the same as the factory.

- Faults that could compromise system performance must be identified at the highest level.

- High valve items must be put back into service as quickly as possible. This means good assemblies are not used to fault isolate failed assemblies.

- Downward compatibility requires that the tests isolate a fault to the next lowest assembly.

- Interchangeability requirement is the same as the Factory.

Figure 21. Controllable Parameters

These are the parameters that can be varied to meet the test objectives:

- Partitioning defines how functions are grouped - the circuit layouts, accessibility, etc. This is a high payoff area sometimes referred to as designing for testability.

- Test point selection - the test points selected have a direct effect on the testability of the item.

- The test equipment determines what can be measured, how quickly measurements can be made, what information can be extracted and displayed. It also influences how quickly and accurately decisions can be made.

- Test methods define what parameters are being measured.

Figure 22. Test Development Methodology

This is a flow diagram of how the tests for the MX IMU were developed and are being refined.

- IMU DESIGN

  The design of the IMU is the principle driver.

- MAINTENANCE PHILOSOPHY

  The maintenance philosophy defines how the IMU will be maintained during its operational life.

- FACTORY TEST FLOWS

  These show how the factory plans to build the IMU. They identify where tests will be performed. During the build cycle, the flow is upward.

- DEPOT TEST FLOWS

  These show how the depot plans to fault isolate and repair failed IMUs. These flows are both downward and upward.

- DECISION POINTS

  Decision points are where tests are performed and decisions made. Maintenance philosophy and test flows are modified to create a common set of decision points. This is one step in resolving the differences between maintenance requirements and factory requirements.

- TEST REQUIREMENTS

  These are the performance requirements that the testable items must meet in order that the IMU will meet its performance requirements.

- TEST EQUIPMENT TEST METHODS

  The decision points define what will be tested and the test requirements define the measurements that must be made. These two inputs have a major influence in defining the test equipment and test methods.

- TESTABILITY ANALYSIS

  Testability analysis includes reliability predictions, failure and effects analysis and maintainability analysis, as well as test equipment capabilities, test methods, and test requirements. The output of the testability analysis modifies the

partitioning and test point selection of the IMU design which iterates the whole process.

This is not a trivial process - in the MX IMU program, a number of person years of effort have been expended. Special tradeoff studies have been made to determine what functions go where, what signals should be monitored, how the signals should be monitored, what test equipment should be used, what data should be collected, and how the data should be processed.

As can be seen from the elements involved in the flow diagram, the MX IMU test development is part of the basic design process. When this is done correctly, the result is a product that can be built efficiently, maintained effectively, and used with a high confidence of success.

PART 4. THE STATUS OF THE MX IMU TEST METHODS AND TEST EQUIPMENT

Figure 23. IMU Maintenance Philosophy

This is the maintenance philosophy presently being implemented.

Figures 24 and 25. Decision Points

This shows the points where tests will be performed in the factory and in the depot. The differences between the factory and depot are a result of the depot not repairing hybrids, but repairing TGIIs and hydraulic components.

Figures 26 through 35.

These show the planned test equipment and test methods that will be used to support the decision points.

PART 5. MAINTENANCE OPERATIONS

This is a self-contained audio slide presentation showing the projected maintenance operation. It uses photographs of ADP equipment to demonstrate the steps required to fault isolate and repair an IMU.

CONTENTS

- IFSS RELIABILITY REQUIREMENTS
- PARTS SELECTION ALTERNATIVES
- COST OF ELECTRONIC PARTS VS FAILURE RATES
- PARTS COST TRADE OFF FOR MULTIPLEXER MASTER UNIT (MUX)
- PARTS COST TRADE OFF FOR IFSS AIRBORNE EQUIPMENT
  - DURING PRELAUNCH CHECKOUT
  - DURING FLIGHT TEST
  - COMBINED PRELAUNCH AND FLIGHT TEST
- IFSS RELIABILITY PERDICTIONS
- CONCLUSIONS
- RECOMMENDATIONS

- IFSS RELIABILITY REQUIREMENTS
  - PRELAUNCH AND FLIGHT RELIABILITY (1 HOUR PRELAUNCH, 35 MIN. FLIGHT)

	RELIABILITY
IFSS	0.980
TELEMETRY FUNCTION	0.981
TELEMETRY G&C DATA	0.999
FSS	
TRACKING FUNCTION	0.995
FLIGHT TERMINATION	0.999

  - FIELD RELIABILITY

    500 HOURS MTBF PRELAUNCH

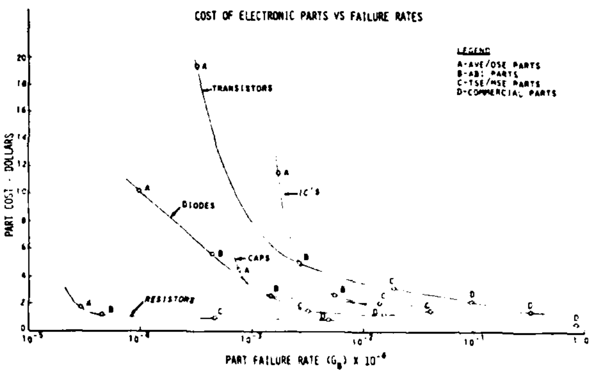
- PART SELECTION ALTERNATIVES

SAMSO-STD-77-7, TABLE II, SELECTION CRITERIA

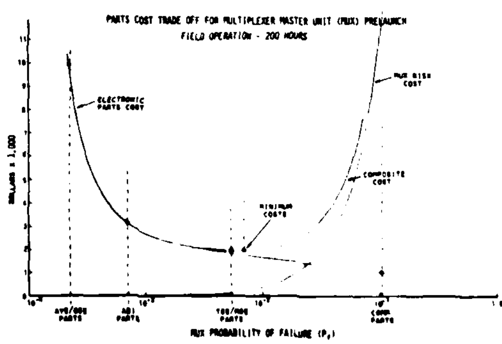
PART TYPE	AVE/OSE	ABI*	TSE / MSE	NONE
IC's	MX HI-REL	MIL-M-38510 CLASS "B"	MIL-M-38510 CLASS "C"	COMMERCIAL SPEC.
TRANSISTORS	MX HI-REL	JAN-TXV JAN-TX	JAN-	COMMERCIAL SPEC.
DIODES	MX HI-REL	JAN-TXV JAN-TX	JAN-	COMMERCIAL SPEC.
RESISTORS	ER MIL-"S"	ER MIL-"S" ER MIL-"R"	ER MIL-"P" ER MIL-"M"	COMMERCIAL SPEC.
CAPACITORS	MX HI-REL ER MIL-"S"	ER MIL-"S" ER MIL-"R"	ER MIL-"P" ER MIL-"M"	COMMERCIAL SPEC.

* CURRENT CONTRACT REQUIREMENT.

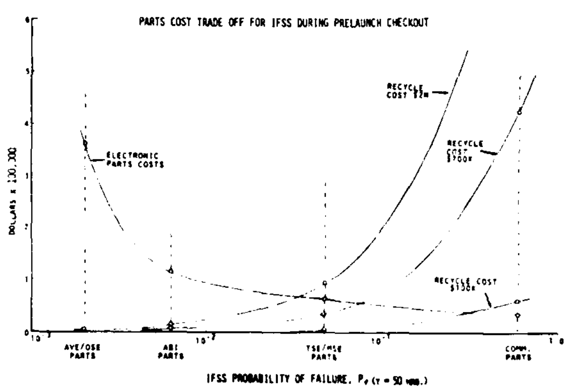
- COST OF ELECTRONIC PARTS VS FAILURE RATES
  - ASSUMPTIONS AND CONDITIONS
    - ELECTRONIC PARTS ARE THE PRINCIPAL CONTRIBUTOR TO IFSS UNRELIABILITY.
    - PARTS COSTS ARE BASED ON AVERAGES OF 1978 PRICING INFORMATION FROM MAJOR SUPPLIERS.
    - PARTS FAILURE RATES FOR HI-REL PARTS BASED ON M^2 EXPERIENCE. (AUTONETICS, APRIL 1978)
    - PARTS FAILURE RATES FOR MIL SPEC PARTS BASED ON MIL-HDBK-217B.

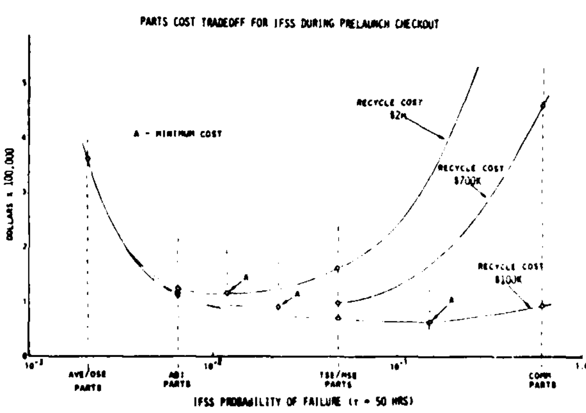


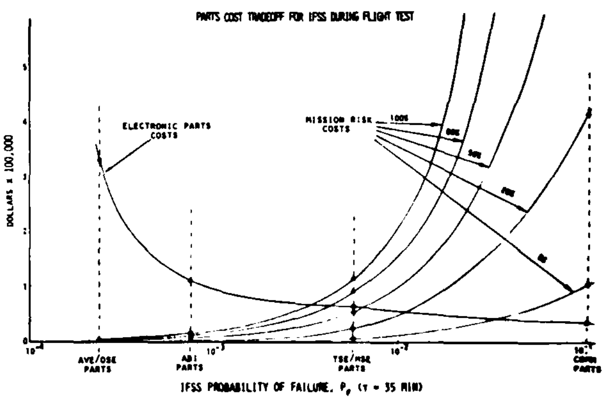
- PART COST TRADE OFF FOR MULTIPLEXER MASTER UNIT (MUX) PRELAUNCH
  - ASSUMPTIONS AND CONDITIONS
    - THE MUX IS REPRESENTATIVE OF IFSS/ABI ELECTRONICS.
    - THE MUX WILL BE SIMILAR TO THE LGM-30 PCM MULTIPLEXER.
    - THE COST OF THE MUX IS ESTIMATED AT $125,000.
    - RISK COST IS DEFINED AS MUX COSTS X PROBABILITY OF FAILURE
    - TOTAL MUX OPERATING TIME IS 200 HOURS.

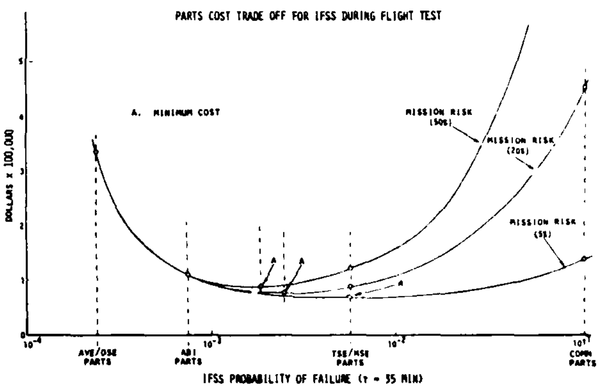


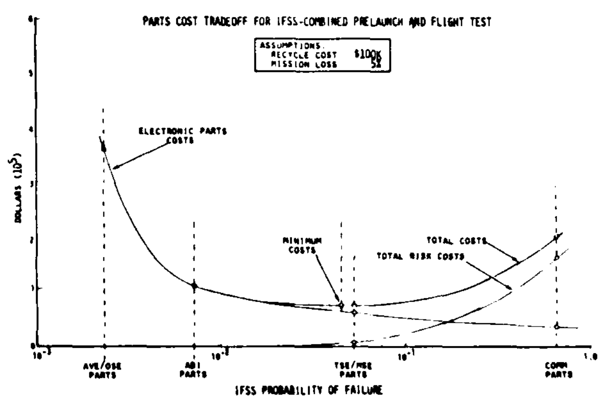
- PARTS COST TRADE OFF FOR IFSS PRELAUNCH AND FLIGHT
  - ASSUMPTIONS AND CONDITIONS
    - THE PROPOSAL BASELINE CONFIGURATIONS WAS ASSUMED.
    - THE IFSS IS EQUIVALENT TO 36.4 MUX UNITS BY ANALYSIS.
    - RISK COST IS DEFINED AS COST IMPACT X PROBABILITY OF IFSS FAILURE.
    - THE COST OF AN MX MISSILE FLIGHT TEST IS ESTIMATED AT $20M.
    - PRELAUNCH CHECKOUT OPERATION OF IFSS IS 50 HOURS.
    - FLIGHT OPERATION OF IFSS IS 35 MINUTES.
    - MISSION RECYCLE COST: LOWER ESTIMATE - $100K, MEDIUM ESTIMATE - $700K, UPPER ESTIMATE - $2M.

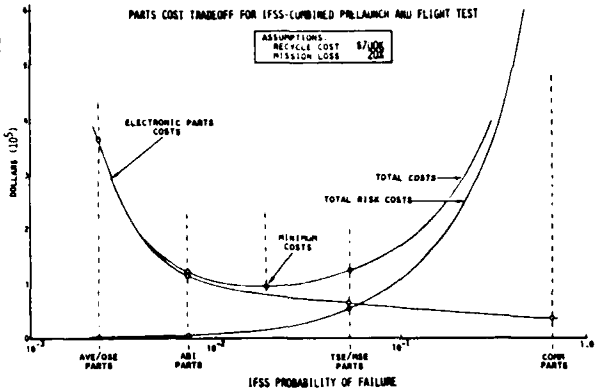


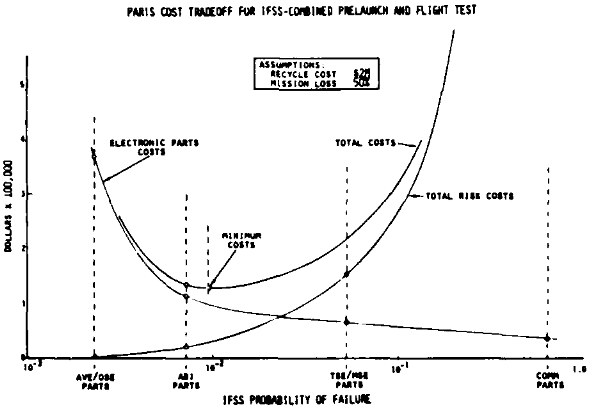












- IFSS RELIABILITY PERDICTIONS VS REQUIREMENTS USING ABI PARTS

	PRELAUNCH AND FLIGHT RELIABILITY*		FIELD RELIABILITY (MTBF)	
	PREDICTION **	PID REQUIREMENT	PREDICTION **	PID REQUIREMENT
IFSS	0.996	0.980	≥ 500 HOURS	500 HOURS
TELEMETRY FUNCTION	0.996	0.981	-	-
TELEMETRY G&C *** DATA	0.999	0.999	-	-
FSS	-	-	-	-
TRACKING FUNCTION	0.999	0.995	-	-
FLIGHT *** TERMINATION	0.999	0.999	-	-

*WITH ABI PARTS **(INDEPENDENT TRW PREDICTION) ***FLIGHT SAFETY REQUIREMENT

- IFSS RELIABILITY PERDICTIONS VS REQUIREMENTS USING TSE/MSE PARTS

	PRELAUNCH & FLIGHT RELIABILITY*		FIELD RELIABILITY (MTBF)	
	PREDICTION	PID REQUIREMENT	PREDICTION	PID REQUIREMENT
IFSS	0.970	0.980	70 HRS	500 HRS
TELEMETRY FUNCTION	0.974	0.981		-
TELEMETRY G&C **	0.993	0.999		-
FSS		-		-
TRACKING FUNCTION	0.995	0.995		-
FLIGHT TERMINATION**	0.997	0.999		-

* WITH TSE/MSE PARTS ** FLIGHT SAFETY REQUIREMENT

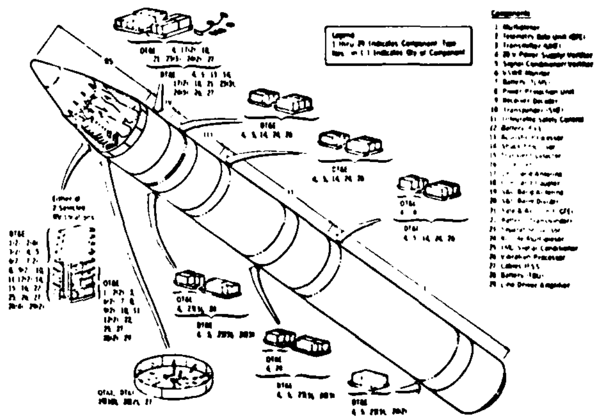
CONCLUSIONS:

- WITH COMMERCIAL PARTS, THE PROBABILITY OF FAILURE IS EXCESSIVE. MISSILE RECYCLE COST AND MISSION RISK COSTS ARE PROHIBITIVE.
- WITH TSE/MSE PARTS, THE PREDICTED RELIABILITY FALLS SUBSTANTIALLY BELOW REQUIREMENTS
- WITH ABI PARTS, THE RELIABILITY MEETS SYSTEM REQUIREMENTS WHILE TOTAL COSTS ARE NEAR MINIMUM.
- WITH AVE/OSE PARTS, THE PROBABILITY OF FAILURE IS DECREASED BY A FACTOR OF 3 OVER THAT OF ABI PARTS AT AN INCREASED COST OF $250,000 PER SYSTEM.

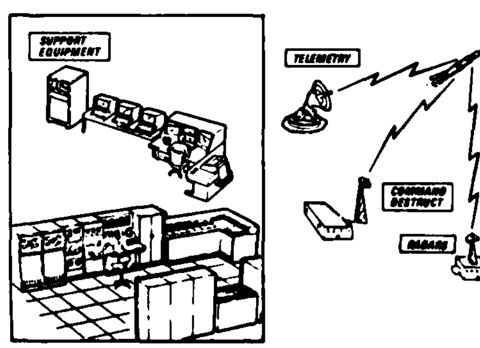
RECOMMENDATION:

- USE ABI LEVEL PARTS AS CURRENTLY SPECIFIED.
- REQUIRE CONTRACTOR TO PROVIDE JUSTIFICATION FOR ANY PLANNED USE OF HI-REL PARTS IN IFSS HARDWARE.

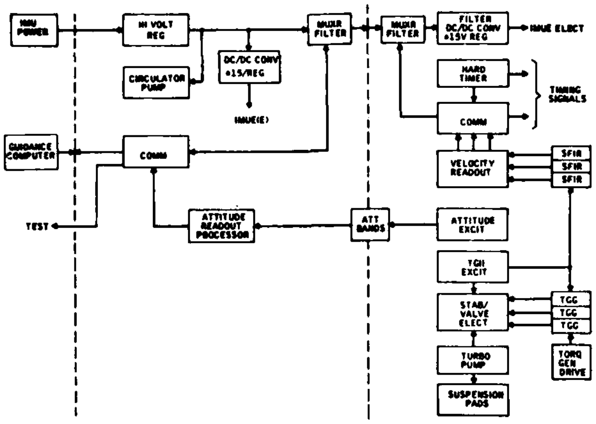
IFSS Physical Installation

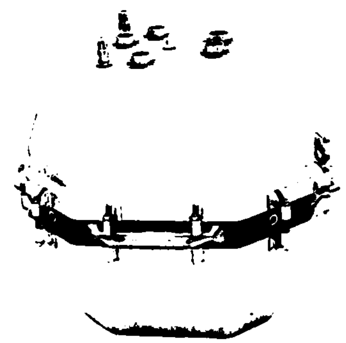


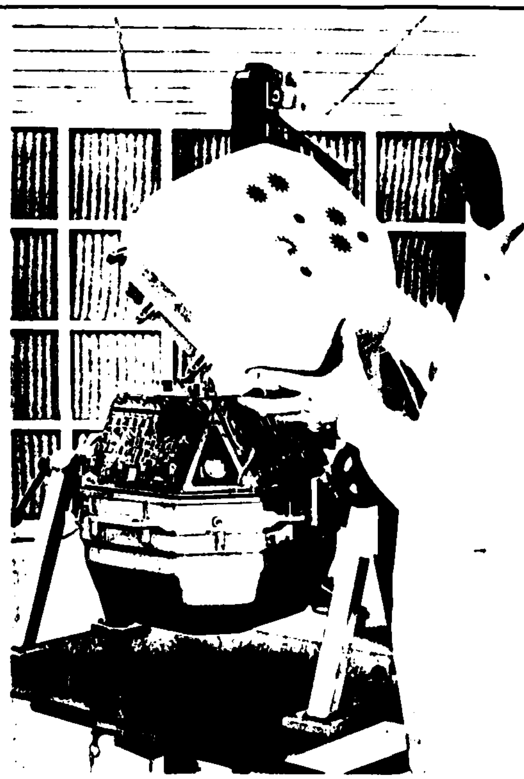
INSTRUMENTATION AND FLIGHT SAFETY SYSTEM

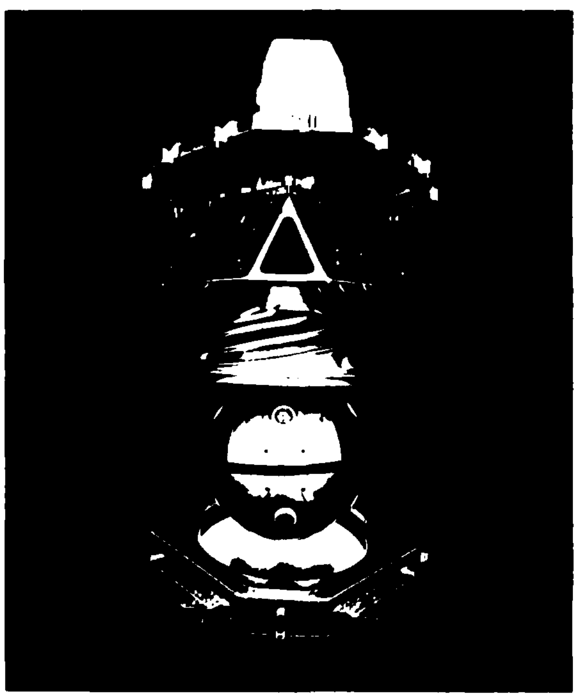


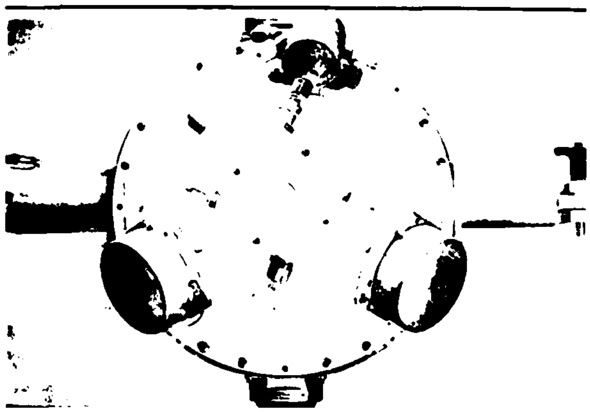
IMU ELECTRONICS BLOCK DIAGRAM

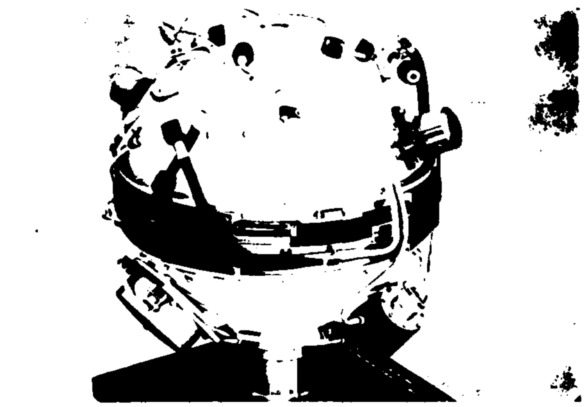
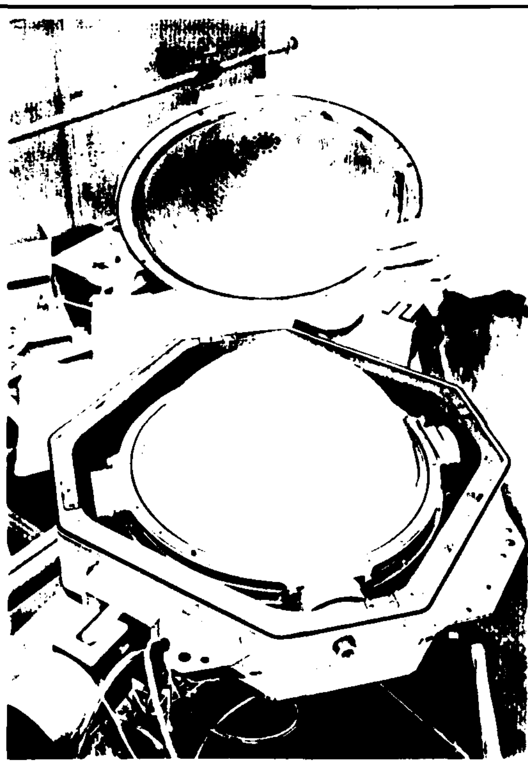


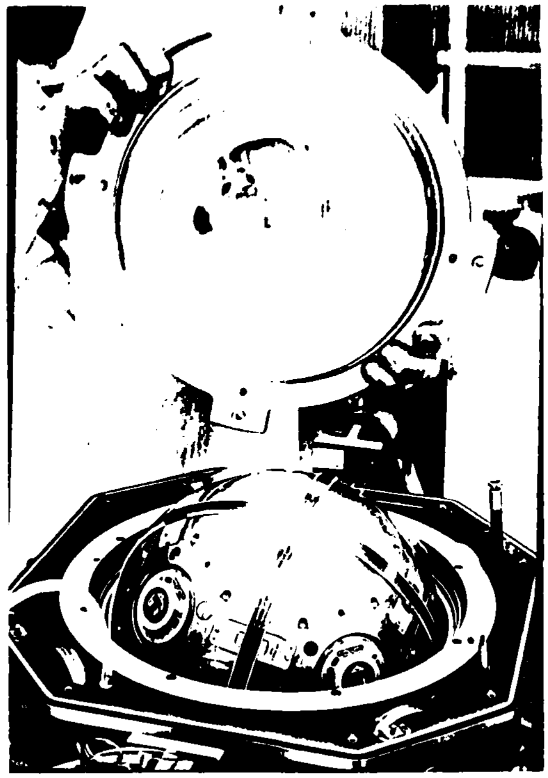
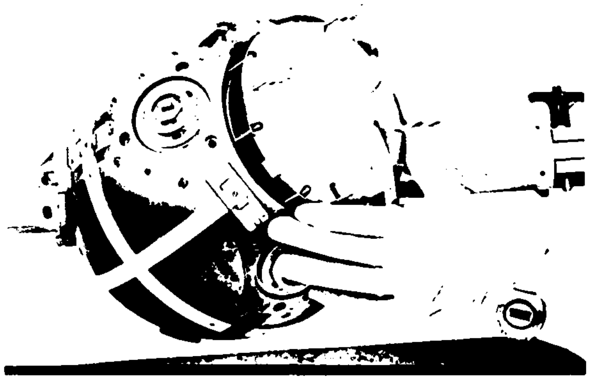
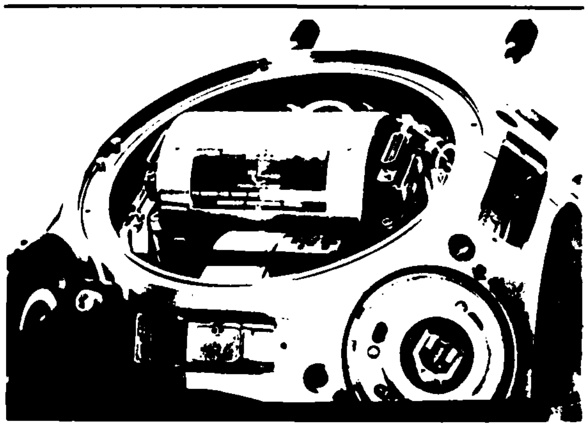


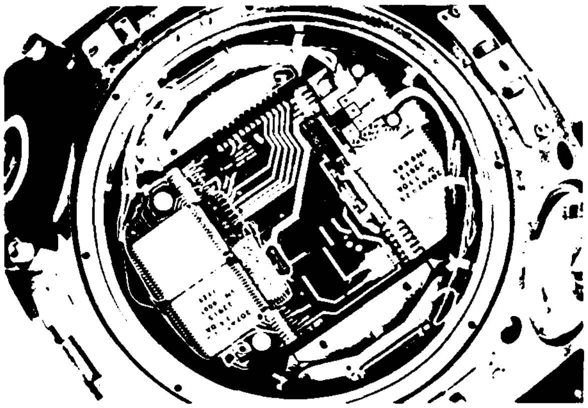


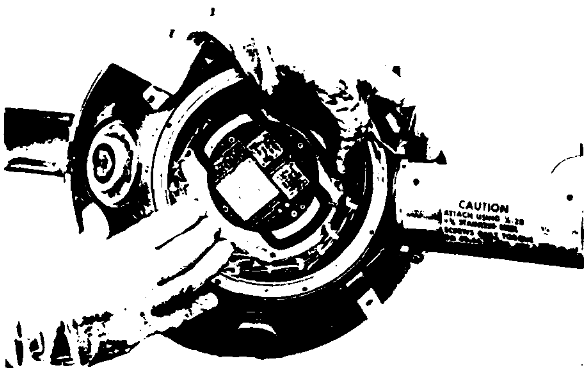


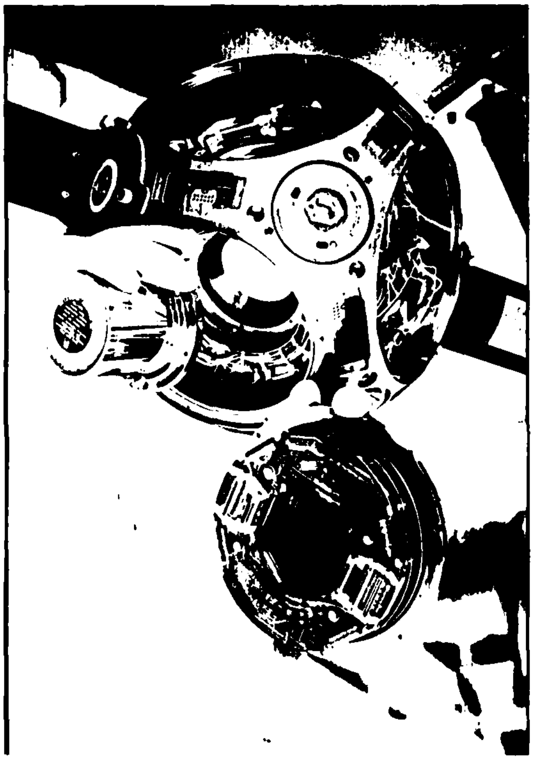


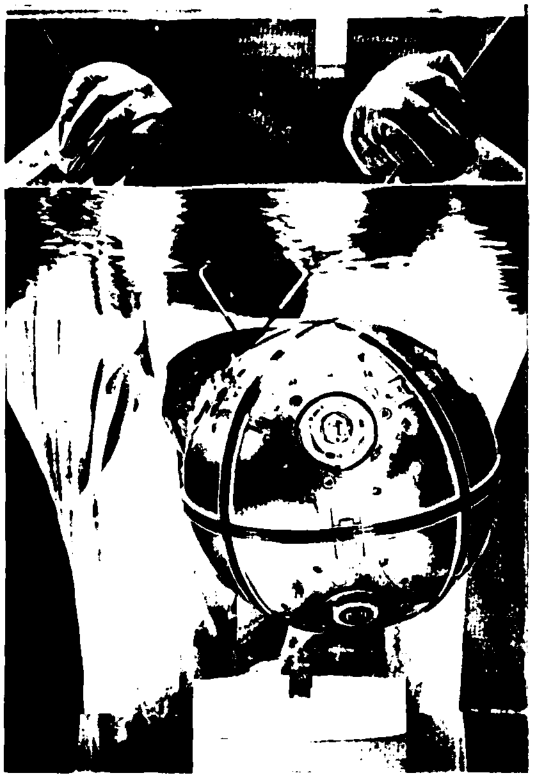






CAUTION





MX IMU TEST OBJECTIVES

- INSURE IMU MEETS PERFORMANCE REQUIREMENTS
- TESTS MEET FACTORY REQUIREMENTS
- TESTS MEET MAINTENANCE REQUIREMENTS
- MINIMIZE LIFE CYCLE COST

PERFORMANCE REQUIREMENTS

- SYSTEM ACCURACY
- RELIABILITY
- INTERCHANGEABILITY

FACTORY REQUIREMENTS

- SYSTEM ACCURACY
- RELIABILITY
- UPWARD COMPATIBILITY
- IDENTIFY FAULTS AT LOWEST LEVEL
- INTERCHANGEABILITY

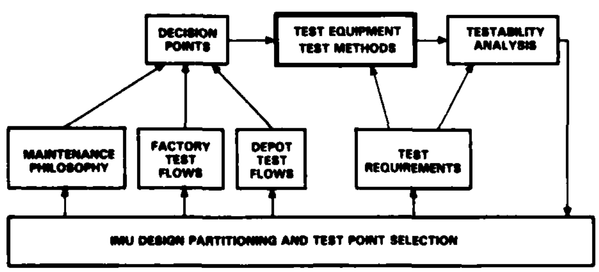
MAINTENANCE REQUIREMENTS

- SYSTEM ACCURACY
- IDENTIFY FAULTS AT HIGHEST LEVEL
- MINIMIZE DOWN TIME
- DOWNWARD COMPATIBILITY
- INTERCHANGEABILITY

CONTROLLABLE PARAMETERS

- SYSTEM PARTITIONING
- TEST POINT SELECTION
- TEST EQUIPMENT
- TEST METHODS

TEST DEVELOPMENT METHODOLOGY



IMU MAINTENANCE PHILOSOPHY

LEVEL

ORGANIZATIONAL	- NO PLANNED IMU MAINTENANCE
INTERMEDIATE	- NO PLANNED IMU MAINTENANCE TRANSPORTED TO DEPOT IN MGCS DRAWER
DEPOT	- REMOVE AND REPLACE ASSEMBLIES BASED ON FAILURE DATA
	FUNCTIONAL TEST, REMOVE AND REPLACE ASSEMBLIES
	RETURN IMU TO USE
	REPAIR ASSEMBLIES BY REPLACING FAILED PARTS

DECISION POINTS

TEST ITEM	FACTORY (NED)	DEPOT
HYBRID MATERIAL	X	
IN-PROCESS HYBRID	X	
HYBRIDS	X	X
TGII MATERIAL		X
IN-PROCESS TGII		X
TGII	X	X
HYDRAULIC MATERIAL		X
IN-PROCESS HYDRAULIC		X
MECHANICAL PARTS	X	X
ELECTRICAL PARTS	X	X
CBA's	X	X
ASSEMBLIES	X	X
EXTERNAL ELECTRONICS	X	X
STABLE MEMBER	X	X
SPHERE ASSEMBLY	X	X
IMU	X	X

IN-PROCESS HYBRIDS

TEST EQUIPMENT	COMMERCIAL ATE
	INTERFACE ADAPTERS
	BURN-IN FIXTURES
TEST METHODS	PARAMETRIC (THERMAL)
	PARAMETER DRIFT SCREENING
	BURN-IN
	THERMAL CYCLE
SOFTWARE	PARAMETRIC TEST
	DIAGNOSTICS
	DATA BASE

HYBRIDS

TEST EQUIPMENT	COMMERCIAL ATE
	INTERFACE ADAPTERS
TEST METHODS	PARAMETRIC (THERMAL)
SOFTWARE	PARAMETRIC TEST
	DATA BASE

TG II

TEST EQUIPMENT*	COMMERCIAL ATE
	INTERFACE ADAPTERS
	PRECISION FIXTURES
TEST METHODS	PARAMETRIC
	PRELIMINARY CALIBRATION
SOFTWARE	PARAMETRIC TEST
	PRELIMINARY CALIBRATION
	DATA BASE

* SAME AS MANUFACTURER

HYDRAULIC ELEMENTS

TEST EQUIPMENT	SEMI-AUTOMATIC (SPECIAL)
	INTERFACE ADAPTERS
TEST METHODS	PARAMETRIC
SOFTWARE	DATA BASE

CBA's

TEST EQUIPMENT	COMMERCIAL ATE
	INTERFACE ADAPTERS
TEST METHODS	PARAMETRIC
	THERMAL CYCLE
SOFTWARE	PARAMETRIC TEST
	DIAGNOSTICS*
	DATA BASE

* FAULT ISOLATE TO PART WITHOUT PROBING

ASSEMBLIES

TEST EQUIPMENT	COMMERCIAL ATE
	SEMI-AUTOMATIC (SPECIAL)*
	INTERFACE ADAPTERS
TEST METHODS	PARAMETRIC
SOFTWARE	PARAMETRIC TEST
	DIAGNOSTICS**
	DATA BASE

* HYDRAULIC ASSEMBLIES

** FAULT ISOLATE TO THE NEXT LOWER ASSEMBLY

EXTERNAL ELECTRONICS

TEST EQUIPMENT	COMMERCIAL ATE
	INTERFACE ADAPTER
TEST METHODS	PARAMETRIC
SOFTWARE	PARAMETRIC TEST
	DIAGNOSTIC*
	DATA BASE

* FAULT ISOLATE TO NEXT LOWER ASSEMBLY

STABLE MEMBER

TEST EQUIPMENT	COMPUTER
	INTERFACE ADAPTER
	ELECTRONIC SIMULATOR
	HOLDING FIXTURE
TEST METHODS	PARAMETRIC
	SECOND CALIBRATION
SOFTWARE	PARAMETRIC
	CALIBRATION
	DIAGNOSTICS*
	DATA BASE

* FAULT ISOLATE TO CAVITY, THRUST VALVE ASSEMBLY OR ATTITUDE BAND.

SPHERE ASSEMBLY

TEST EQUIPMENT	COMPUTER*
	INTERFACE ADAPTER*
	ELECTRONIC SIMULATOR*
	HOLDING FIXTURE
	THERMAL CONTROL
TEST METHODS	PARAMETRIC*
	SECOND CALIBRATION*
	VERIFICATION
SOFTWARE	PARAMETRIC
	CALIBRATION
	VERIFICATION
	DIAGNOSTICS*
	DATA BASE

* SAME AS STABLE MEMBER

IMU

TEST EQUIPMENT	COMPUTER*
	INTERFACE ADAPTER*
	HOLDING FIXTURES
	SHAKER
	REFRIGERANT
TEST METHODS	PARAMETRIC
	FINAL CALIBRATION
	VIBRATION
SOFTWARE	PARAMETRIC
	CALIBRATION
	VIBRATION
	DIAGNOSTICS**
	DATA BASE

* SAME AS STABLE MEMBER

** FAULT ISOLATION TO EXTERNAL ELECTRONICS, SPHERE ASSEMBLY, STABLE MEMBER, CAVITY, THRUST VALVE ASSEMBLY, OR ATTITUDE BAND ASSEMBLY.

PROVISIONS FOR NORMALLY POWER-OFF (DORMANT) ELEMENTS OF ICBM SYSTEMS TO ASSURE OPERATIONAL PERFORMANCE

by

Loren D. Dierking and
Robert F. Nease

Autonetics Strategic Systems Division
Rockwell International

BACKGROUND

The brief study referenced herein was undertaken during the early R&D phase of the MX missile development program. The study pertains to a segment of the guidance and control (G&C) electronics which was to be mounted "downstage" – in this particular case, in a box mounted on Stage I and in a box mounted on Stage II. These electronics, called Servo Amplifier Assemblies (SAAs), are depicted by cross-hatched blocks in Figure 1.

The SAAs provide the rather simple function of interfacing between the "upstage" G&C electronics and the pitch and yaw turbo-mechanical thrust vector actuators (TVAs) which position the single moveable nozzles employed by Stages I and II. The "drive" signals from the upstage G&C are in the form of low-level fixed amplitude pulsewidth-modulated signals, and these signals need only be converted to higher power levels to operate the clutch drive motors of the TVAs. The principal reasons for locating these SAA electronics downstage is to avoid high current flow in long segments of cabling and to take advantage of the payload efficiency of providing power from downstage sources rather than from upstage. In regard to this latter, the SAAs derive their primary power by rectifying the output of a three-phase alternator which is a part of the TVA system. Also, the SAAs provide a simple speed-control function for the hot-gas turbine drive of the TVAs. These SAA functions are depicted in the block diagram of Figure 2. Preliminary design studies indicate that each of these SAAs would have approximately 800 electronic parts, many with high current ratings.

As a result of physical constraints of the installation and other application matters, the turbo-mechanical TVAs cannot be tested, or operated, after the stage has been assembled into the missile – until their operation during booster flight. Thus, unless special provisions are made specifically for this purpose, the SAAs cannot be tested, or even powered, during the pre-launch period of weapon system operation. These various operating concepts and constraints resulted in the formulation of a rather well-defined trade study to determine whether or not to include provisions for pre-launch testability in the design of the SAAs. Since ground-based power and cooling constraints precluded the consideration of continuous pre-launch operation of the SAAs, the trade study was limited to consideration of two basic approaches:

1. Dormant SAAs – that is, SAAs which are neither powered nor tested after missile assembly until the missile is launched, or

2. Semi-Dormant SAAs – that is, SAAs which can be powered up and tested periodically during ground operations of the missile. This design approach is also referred to as the Testable SAA.

Although dormant and semi-dormant design approaches could have covered a wide range of designs/capabilities, it will be noted in the following section that only one design concept was considered seriously for each of these approaches. Before proceeding, it is also worthy of note that there was probably some significant prejudice existing – both with this contractor and our customer – in favor of the semi-dormant approach, since this was the approach used on all three Minuteman programs for downstage mounted flight control electronics. But more about this in a later section.

SAA TESTABILITY TRADES

In addition to cost, size, weight, and other obvious parameters which were to be compared in this trade of test vs no-test (or semi-dormant vs dormant) SAA designs, there are three requirements/constraints on the G&C system (of which the SAAs are a part) which could be significantly influenced by SAA performance. These are:

1. P_S. The G&C system must have a probability of successful flight and launch (called P_S) which exceeds a specified value. That is, whichever SAA approach is selected must provide a box-level P_S which is consistent with this G&C system requirement. Although not required by contract, a tentative P_S allocation for

Similarly, using postulated failure rates for dormant components, the MIL Handbook-type procedures were used to estimate P_S for the dormant version of the SAA. In this case, it was found that P_S for the dormant SAA was marginally acceptable after several years of deployment. However, the expected "maturation" of the P_S for the two different versions of the SAAs was considered to be distinctly different, as shown conceptually in Figures 6 and 7. More specifically, it is expected that the greater exposure experienced with the testable SAA during R&D and early operational use will allow the "bugs" to be removed from the testable SAA hardware more quickly than they will be removed from the dormant SAA hardware. Also, Figure 7 shows the gradual reduction in P_S with passage of time which can be expected with the dormant SAA.

SUMMARY

In summary, it was concluded that either approach could be made to work, with costs favoring the dormant SAA concept, and predicted reliability performance favoring the testable SAA concept. The testable SAA approach was favored for the following reasons:

- Hardware maturity is likely to be achieved earlier in the program.
- Surprises and disappointments are less likely.
- Generally improved confidence in hardware performance can be obtained with only modest increase in cost.

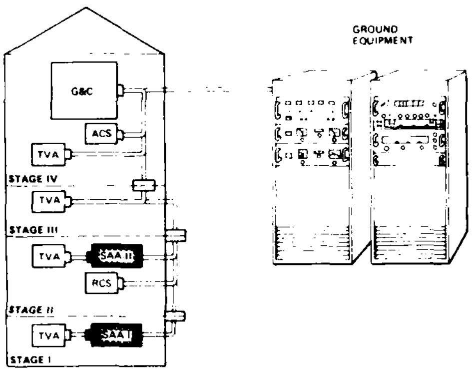


Figure 1. Missile Flight Control Subsystem

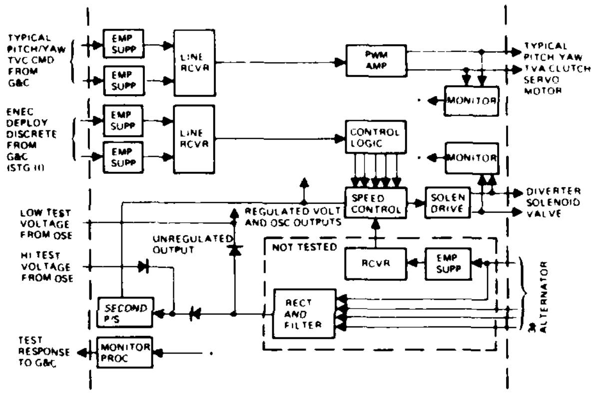


Figure 3. Testable SAA Block Diagram

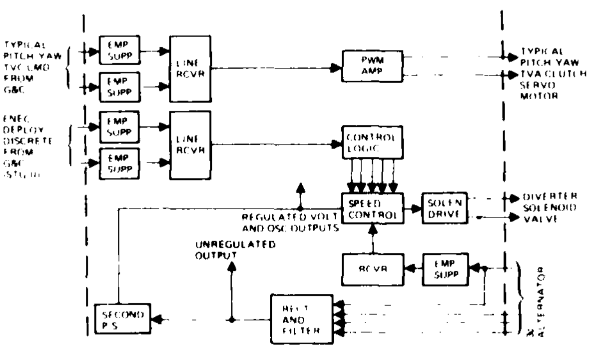


Figure 2. Dormant SAA Block Diagram

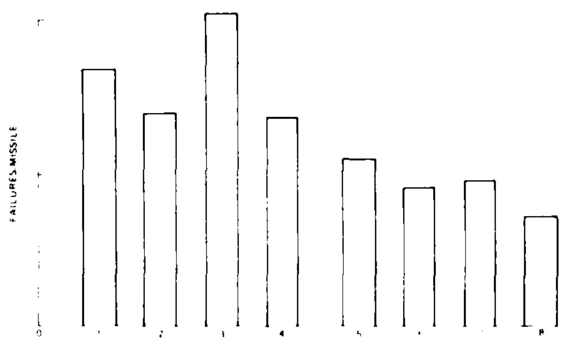


Figure 4. Missile F/C Hazard Rate at Missile Assembly

the SAAs had been established by the contractor.

2. MTBF. The G&C system must achieve a pre-launch reliability of at least a specified value for meantime between failure (or MTBF). Again, a tentative allocation of this system-level requirement to the SAA was available for the trade studies. Obviously, this reliability requirement is pertinent only to the testable (or semi-dormant) version of the SAA, since the dormant SAA cannot fail during pre-launch missile operations.

3. Fault Isolation. G&C faults detected during pre-launch operations must be isolated to the faulty line-replaceable unit (LRU) through monitoring, self-test, and status reporting, with positive identification of 95 percent of all failures. As with the MTBF requirement, this requirement is important only to the semi-dormant version of the SAA.

After a brief review of the two general versions of the SAAs, it was determined that the two concepts could be rather well defined as follows:

- The dormant (or non-testable) version was as defined in the block diagram of Figure 2 – without the addition of redundant elements, due to weight/size limitations.

- The semi-dormant (or testable) version was defined such that almost all (approximately 95 percent) of the SAA functions could be tested. The block diagram for this semi-dormant version of the SAA is shown in Figure 3.

Thus, these two specific concepts for the dormant and semi-dormant SAAs represent what were considered to be extremes for the two approaches. Also, the major differences/changes in the programs for the two versions of SAAs were defined as described below.

Unique Aspects of Dormant SAA Program

- Additional acceptance tests for dormant SAAs were defined to provide increased exposure of this hardware prior to delivery.

- A reliability surveillance program was added to provide post-delivery monitoring of this dormant hardware. This program involved the testing of 10 or more "aged" SAAs each year. It was considered that this testing would be non-destructive and that each test specimen could be returned to operational inventory after the sample testing.

- The SAAs probability of successful launch and flight (P_S) tends to degrade with time after their installation in the missile, due to presumed failure rate of parts under power-off conditions. This P_S could be "reset" by the recycle of deployed missiles and changeout/test of SAAs, but at significant expense.

Unique Aspects of Semi-Dormant (Testable) SAA Program

- Approximately 95 percent of the SAA function is verified in periodic (say, monthly) missile test. This test provision added approximately 15 percent to the electronics parts count, and only a small increase in size/weight of the box. This provision for testing also added approximately 20 percent to the wire count of the missile cables and added a ground power supply for such testing.

- As a result of periodic testing, the failure of an SAA can be detected and the failed SAAs must be replaced, at significant expense. Such failures must be included in the allowable G&C MTBF. Also, any detected faults must be properly isolated between the upstage and downstage elements, and they had to be accounted for in the definition of the test circuitry for the testable SAA.

- This periodic testing (and changeout of failed SAAs) should give rise to a Ps for the testable SAA which is considerably higher than that for a dormant SAA after prolonged periods of deployment.

This somewhat restricted definition of the two competing concepts allowed a rather simple

comparison of the two approaches without getting bogged down in the myriad versions of each concept which might have been considered. Further refinements in the concepts (such as the addition of some redundancy for the dormant scheme) would be considered later if either concept did not meet the top-level requirements/constraints.

REVIEW OF MINUTEMAN III EXPERIENCE

Before proceeding with the trade study comparisons, it was considered appropriate to reflect upon the experience occasioned by the development and deployment of the Minuteman III downstage flight control hardware. This data base was selected for two primary reasons: 1) the reliability performance of this hardware was judged to be representative of that for a program which uses high-quality parts and employs an effective corrective action program, and 2) the failure removal data were considered to be complete and readily available. Before presenting the data, it should be noted that this assessment included the TVA hardware and associated downstage electronics for all three stages of the booster. Thus, the complexity of this hardware is several times that of the SAA box under consideration. Also, it should be noted that all of this hardware, including TVAs, is thoroughly tested during missile assembly and during periodic missile test in silo operation.

The first data which were reviewed pertained to the testing of this flight control hardware during initial assembly of the missile at Plant 77, located at Hill Air Force Base. During eight years of missile assembly work, it was found that the downstage flight control hardware experienced approximately one failure for every 12.5 missiles assembled, or a hazard rate for the downstage flight control hardware of approximately 8 percent per missile.

As this hazard rate was broken down by calendar years, it was found that some improvement was experienced as the program matured, as shown in Figure 4; however, even in the later years of the program, the hazard rate was still significant. Since a failure rate of downstage flight control hardware on the order of 8 percent would be unacceptable for a totally dormant flight control system, it is easily seen that additional pre-delivery test/inspection procedures would have been required to make the Minuteman III flight control hardware operate acceptably in a dormant application. This supported our initial thoughts that a successful dormant SSA program must involve more thorough pre-delivery testing than would be required for a successful testable SAA program.

The second set of Minuteman III data reviewed was the in-silo failure rate data for the downstage flight control hardware. It was found that this hardware in the first seven years of silo deployment failed at an average rate of approximately 1.5 percent of the deployed missiles per year of operation. In this case, the breakdown of failure rate by years showed a more interesting situation, as shown in Figure 5. The failure rate in the first three years of silo use was significantly greater than that for subsequent use. This experience was directly related to two time-dependent failure modes which were not experienced during the R&D program, but which were then identified and fixed during the production program. This sort of experience provided emphasis on the reliability surveillance effort, which was also considered to be necessary for a successful dormant SAA program.

RESULTS OF SAA TESTABILITY TRADES

The major results of the SAA testability trades are summarized below.

Comparison of Program Costs

Overall program costs for SAA-related efforts were found to be from 5 to 10 percent higher for the testable SAA than for the dormant SAA. The major portions of these added costs were attributed to deliverable SAA hardware itself, both during R&D and the production phases of the program. Support costs attributable to the testable features of this version of the SAA were found to be a minor effect. The cost of the reliability surveillance efforts for the dormant SAA program was significant, but it did not completely offset the costs of the added complexity of the testable SAAs. If this sample testing had been assumed to be destructive, the cost of the dormant SAA program would have exceeded that for the testable SAA program.

Comparison of Reliability Performance Predictions

MIL Handbook procedures were used to estimate MTBF and P_S for the testable version of the SAA. The predicted MTBF exceeded that which could be allocated to the SAA, and likewise the predicted P_S exceeded that which could be reasonably allocated to the SAA.

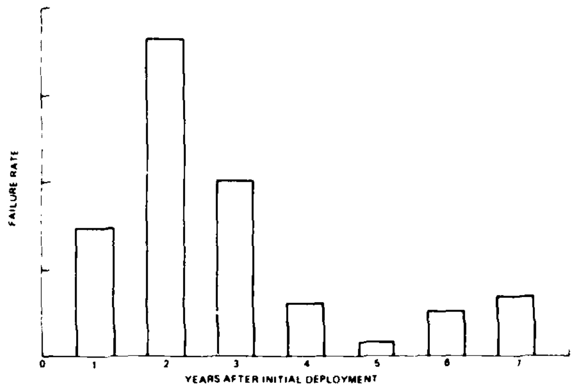


Figure 5. Missile F/C Silo Failure Rate vs Time

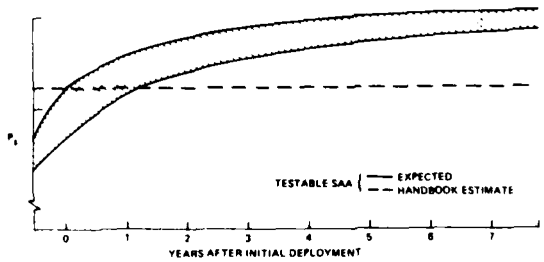


Figure 6. Expected Maturation of Testable SAA

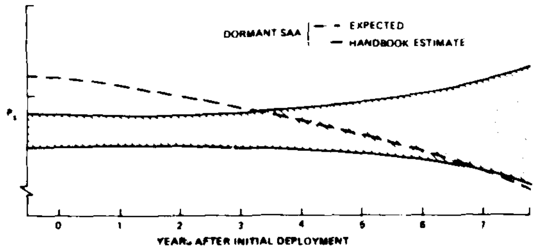


Figure 7. Expected Maturation of Dormant SAA

SUMMARY OF ISSUES AND RECOMMENDATIONS

DEVELOPMENT PROCESS

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Over-lapping Specifications

Issue

Closely similar specifications indicate a need for commonality or standardization of existing specifications to limit development costs. As a by-product fo the cost and schedule sensitivities brought out in workshop discussions, the issue of proliferation and confusion of well-intended specifications was raised. In particular, participants were concerned over electronic piece-part specifications and soldering (craftsmanship) specifications residual to earlier space projects. Many of these have become the agency or company standards of various system organizations in Government and Industry. Such standards are needed as instructions at some lower-tier levels. In others and at major system contractor's plants, they are matters of cost and schedule concern for no-longer -needed variety.

Recommendations

- Industry associations identify to Government the specifications that have over-lapping requirements and/or redundant requirements.

- Government agencies and industry associations intensify their efforts to achieve commonality of specifications used for procurement.

2. Value Analysis

Issue

Value analyze system and mission assurance requirements, particularly in the early program (i.e., conceptual and development).

Discussion from workshop participants supported the general concept of value analysis of assurance requirements early in development planning. Discussion of a cost minimization study leading to choice and specifications of grade of electronic parts showed challenge of complete life cycle cost consequences of such choices. Concern was expressed that there were hidden development process costs consequent on use of less than highest grade parts.

Recommendations

- Require early reviews of system and mission assurance requirements and budgets.

- Tailor specifications in the initial program phase to assure cost effective application to real program requirements.

3. Prototype Concept

Issue

Protoflight development concept. Both Government and Industry representatives contributed to recognition that at least four NASA Centers and two system prime contractors have used the protoflight approach and that it has represented planning initiative from each of Government and Industry.

Recommendations

- Programs consider in conceptual phase the use of a single set of hardware for ground tests and flights.
  - Make risk assessment.
  - Consider weight and power margins.
  - Take advantage of known mission environment.
  - Utilize only experienced contractors.
  - Whenever possible, select proven flight hardware.

WORKSHOP I

COMPUTER SOFTWARE/COMPUTER RESOURCES

Chairmen	Coordinator
Lt. Col Ed Myers, Space Division Mr. Dan Schneider, TRW Mr. David Aichele, NASA	Bob Berri, Aerospace Corp.
Software Management Methods	Mr. Bob Williams, TRW
Plant Representative Methods	Capt George Trevor, AFPRO
Core Concept	Maj Jim Riley, ALD
Thursday, May 1	
Software Quality Assurance	Mr. Dick Evans, 4C Corp
Verification and Validation	A.J. Macina
Air Force Planning	Capt Dave Herriko, AFSC
Working Lunch, Open Discussion, Development of Recommendations	

SOFTWARE MANAGEMENT METHODS

R.D.Williams
TRW
F.S. Ingrassia
TRW

ISSUE: SHOULD SOFTWARE DEVELOPMENT METHODOLOGY BE A CONTRACT COMPLIANCE ITEM?

WHAT IS SOFTWARE DEVELOPMENT METHODOLOGY?

- AN INTEGRATED AND CONSISTENT SET OF POLICIES, PROCEDURES AND PRACTICES SPECIFYING HOW A SOFTWARE PRODUCT WILL BE SPECIFIED, DESIGNED, TESTED, CONTROLLED AND DELIVERED

IT INCLUDES

- MILESTONES AND REVIEWS
- CDRL'S AND DOCUMENTATION REQUIREMENTS
- GOVERNMENT COMPLIANCE DOCUMENTS
- DEVELOPMENT PRACTICES
- TESTING REQUIREMENTS
- CONFIGURATION MANAGEMENT
- QUALITY ASSURANCE
- PROGRAMMING STANDARDS

WHY IS THIS QUESTION AN ISSUE?

- UNFORTUNATELY, RFP'S AND CONTRACTS NOT ONLY SPECIFY WHAT ONE SHOULD DO - BUT TO A GREAT EXTENT, HOW ONE SHOULD DO IT
- THE TREND SEEMS TO BE TOWARD GREATER COMPLIANCE SPECIFICATION RATHER THAN LESS
- BASED ON HIGH LEVEL GOVERNMENT POLICIES THERE HAS BEEN A PROLIFERATION OF IMPLEMENTING DIRECTIVES, LOCALLY DEVELOPED, THAT ARE:
  - BASED ON ORGANIZATION'S OR EVEN INDIVIDUALS'S MOST RECENT EXPERIENCE - BE IT A SUCCESS OR FAILURE
  - BASED ON A SPECIFIC EXPERIENCE WHICH IS GENERALIZED
  - INDEPENDENT OF THE CONTRACTUAL INCENTIVE STRUCTURE
  - BASED ON THE ASSUMPTION THAT IF A CONTRACTOR IS NOT RIGOROUSLY CONTROLLED, HE WILL NOT DELIVER A QUALITY PRODUCT

SECONDARY ISSUE

- THE PROBLEM OF CONSISTENCY, RELEVANCE AND APPLICABILITY OF CURRENT COMPLIANCE ITEMS IN RFP'S
  - ANYONE WHO GETS INVOLVED IN RESPONDING TO GOVERNMENT RFP'S QUICKLY DISCOVERS THAT THEY ARE ALL DIFFERENT
  - EACH ONE APPEARS TO BE A FAIRLY UNIQUE PRODUCT COMPILED BY A UNIQUE GROUP OF PEOPLE
  - IF ONE COULD ATTRIBUTE THESE DIFFERENCES TO TAILORING FOR THE SPECIFIC PROCUREMENTS, THIS WOULD NOT PRESENT A PROBLEM
  - HOWEVER, THE IMPRESSION THAT ONE GETS IS THAT THE DIFFERENCES ARE A RESULT OF THE COLLECTIVE EXPERIENCES AND BACKGROUND OF THE INDIVIDUALS WHO PREPARED THE DOCUMENTS

MILESTONES AND REVIEWS

- THESE CREATE THE BASIC STRUCTURE FOR THE DEVELOPMENT PROCESS
- NATURAL PROGRESSION AND INTER-DEPENDENCY OF KEY EVENTS
  - SRR, SDR, PDR, CDR, ETC.
- THE SCHEDULE AND CONTENT SHOULD REFLECT THE TYPE OF PROCUREMENT AND DEVELOPMENT EFFORT INVOLVED

PROBLEMS –

- THE NUMBER AND SCHEDULE OF THESE EVENTS NOT ALWAYS REALISTIC
  - LIKE HAVING A PDR TOO EARLY
- IF YOU DON'T HAVE THE REQUIREMENTS BASELINED - YOU CAN'T PROCEED EFFECTIVELY
- DISAGREEMENTS AND CONFLICTS ARISE WHEN THE OBJECTIVES, CONTENTS AND CONDUCT OF THESE EVENTS ARE NOT UNDERSTOOD OR AGREED TO BY THE PARTIES INVOLVED
- SOFTWARE DESIGN IS A CLASS II TYPE ACTIVITY - NOT CLASS I
  - CAN'T GET CUSTOMER APPROVAL FOR EVERY DESIGN CHANGE

CDRL'S AND DOCUMENTATION REQUIREMENTS

- THESE GIVE SUBSTANCE TO THE DEVELOPMENT PROCESS
- THEY PROVIDE BOTH CONTRACTUAL AGREEMENTS (BASELINES) AND MANAGEMENT VISIBILITY OF THE DEVELOPMENT PROCESS
- THE TYPE, NUMBER AND CONTENT NEED TO REFLECT THE TYPE OF PROCUREMENT AND DEVELOPMENT EFFORT INVOLVED

PROBLEMS –

- THE NUMBER, ALLOCATION AND DELIVERY SCHEDULES NOT ALWAYS CONSISTENT WITH GOOD DEVELOPMENT APPROACH
  - TOO MANY OR WRONG CHOICE OF CPCI'S
- DELIVERABLES OFTEN TIED TO EVENTS THAT ARE NOT POINT EVENTS
  - CONFUSION AND MISUNDERSTANDING ABOUT DUE DATES
- ASSOCIATED DATA ITEM DESCRIPTIONS OFTEN INAPPROPRIATE OR INADEQUATE TO DESCRIBE DOCUMENTATION
  - EITHER TOO GENERAL, OR MUCH TOO DETAILED AND SPECIFIC
- TOO MUCH EMPHASIS ON THE PAPER ITSELF - AND NOT ENOUGH ON THE CONTENTS OF THE PAPER

COMPLIANCE DOCUMENTS

- THESE SPECIFICALLY ADDRESS THE 'HOW' OF DEVELOPMENT METHODOLOGY
- SOME ARE VERY GENERAL IN NATURE - CAN APPLY TO A WEAPON SYSTEM OR A COMPUTER PROGRAM
- SOME ARE VERY SPECIFIC AND PERHAPS TOO DETAILED IN CONTENT
- TREND SEEMS TO BE TOWARD MORE CONSTRAINTS RATHER THAN LESS

PROBLEMS –

- VERY LITTLE CONSIDERATION OR ENCOURAGEMENT IS GIVEN TO TAILORING FOR THE SPECIFIC APPLICATION OR PROCUREMENT
- THEY IMPOSE STANDARDS AND PRACTICES THAT ARE NOT UNIVERSALLY TRUE OR VALID THAT SHOULD BE AT THE DISCRETION OR CONTROL OF THE CONTRACTOR
- NOT IN TUNE WITH EVOLVING PRACTICES AND NEEDS OF SOFTWARE DEVELOPMENT/MANAGEMENT
- CONTRACTORS BEING FORCED OUT OF THEIR NORMAL DEVELOPMENT MODE

CONTRACTOR SOFTWARE DEVELOPMENT POLICIES

- THESE ADDRESS THE INTERNAL 'WHAT' AND 'HOW' OF DEVELOPMENT METHODOLOGY
- THEY MAY VARY WIDELY IN THEIR QUALITY AND DETAIL
- THEY DO REPRESENT THE CONTRACTOR'S MODE OF OPERATION AND MANAGEMENT

PROBLEMS –

- CONFLICT SITUATION ARISES WHEN COMPLIANCE ITEMS ARE IN DISAGREEMENT WITH CONTRACTOR POLICIES AND PROCEDURES
- THE EXTREME VARIABILITY AMONGST CONTRACTORS MAKES COMPARATIVE EVALUATION DIFFICULT
- WHEN THEY DON'T EXIST CHAOS MAY RESULT DUE TO INCONSISTENT IMPLEMENTATION ACROSS A PROJECT
- THEY SOMETIMES DON'T HAVE THE FLEXIBILITY TO FIT THE PROCUREMENT

RESPONSE TO ISSUE:

NO - SOFTWARE DEVELOPMENT METHODOLOGY CONSTRAINTS SHOULD NOT BE CONTRACT COMPLIANCE ITEMS, AND SHOULD BE REMOVED FROM SPECIFICATIONS, STANDARDS AND DIRECTIVES WHERE THEY OCCUR

THESIS:

THE TIME HAS COME FOR THE GOVERNMENT/INDUSTRY TO TREAT SOFTWARE DEVELOPMENT METHODOLOGY ISSUES AS CRITERIA BY WHICH TO EVALUATE THE CONTRACTOR'S CULTURALLY DEVELOPED SYSTEM, AND NOT AS REQUIREMENTS IN COMPLIANCE DOCUMENTS

RECOMMENDATIONS

1. THE GOVERNMENT SHOULD DISSEMINATE GUIDELINES AND STANDARDS FOR THE PREPARATION OF RFP'S AND INSTITUTE TRAINING PROGRAMS IN THEIR USE.
2. FORM A CENTRAL GROUP IN EACH DEPARTMENT OR AGENCY TO REVIEW RFP'S FOR CONSISTENCY, ADEQUACY AND COMPLIANCE WITH GUIDELINES.
3. LIMIT COMPLIANCE ITEMS TO THOSE THINGS THAT ARE REALLY ESSENTIAL.
4. IN LIEU OF (3) - SOLICIT AND ENCOURAGE TAILORING TO FIT THE PROCUREMENT.
5. ENCOURAGE CONTRACTORS TO DOCUMENT AND PROPOSE THEIR DEVELOPMENT METHODOLOGY AND BE EVALUATED ON IT.
6. ASSURE ABSENCE OF COMPLIANCE ITEMS WHICH ADDRESS *"HOW TO DO IT"* INSTEAD OF *"WHAT IS NEEDED"*.

COMPUTER SOFTWARE CONTRACT ADMINISTRATION

Capt. George Trever
AFPRO-TRW

COMPUTER SOFTWARE CONTRACT ADMINISTRATION OVERVIEW

- APPROACH
- FIELD STUDY
- PLANNING CONSIDERATIONS

COMPUTER SOFTWARE CONTRACT ADMINISTRATION APPROACH

- CONDUCT STUDY
  - FRESH LOOK AT MANAGEMENT TOOLS
  - FIELD TEST IDEAS
- INVOLVE ALL FIELD DETACHMENTS
- ADDRESS ALL COMPUTER SOFTWARE

AFCMD MANAGEMENT TOOLS

- CONTRACTOR'S MANAGEMENT SYSTEM EVALUATION PROGRAM (CMSEP)
  - AFCMD REGULATION 178-1
- DIRECT SUPPORT TO BUYING AGENCY
  - DEFENSE ACQUISITION REGULATION (DAR) 1-406
  - MEMORANDUMs OF AGREEMENT (MOA)

CMSEP OVERVIEW

- WHAT IS CMSEP?
  - AN EXISTING AFCMD MANAGEMENT TOOL
  - PROVIDES A HEALTH CHECK ON CONTRACTOR'S MANAGEMENT SYSTEMS
  - IMPOSED AT ALL AFPROs
- WHAT DOES CMSEP PROVIDE?
  - ASSURES DOCUMENTATION AND USE OF SOUND MANAGEMENT PRACTICES
  - PROMOTES PREVENTATIVE MAINTENANCE OF MANAGEMENT SYSTEMS

AFCMD FIELD STUDY

- CONDUCTED BY AIR FORCE PLANT REPRESENTATIVE OFFICE (AFPRO) AT TRW, REDONDO BEACH, CA.
- LIMITED TO ENGINEERING AND QUALITY ASSURANCE FUNCTIONS
- ACTIVE PARTICIPATION BY TRW AND HQ AFCMD
- OBJECTIVE:
  - IMPROVE CMSE PROGRAM
  - DETAIL DIRECT SUPPORT FUNCTIONS

SOFTWARE ENVIRONMENT

TYPE OF SOFTWARE	DELIVERABLE TO THE GOVERNMENT	NONDELIVERABLE TO THE GOVERNMENT
SYSTEM (CPCI)	X	N/A
TEST (CPCI) ATE	X	N/A
TEST SUPPORT CAT CAI	X	X
FIRMWARE HWR INTENSIVE SW INTENSIVE	X	X
ENGINEERING SUPPORT MODELING SIMULATIONS	X	X
COMPUTER OPERATING SYSTEMS	X	X
CAD/CAM SYSTEMS	N/A	X

TEST MANAGEMENT SYSTEM INDICATORS (MSIs)

MSI 1 DESIGN MANAGEMENT

- SW REQUIREMENTS
- DESIGN REVIEWS
- PROGRAMMING STANDARDS
- INTERNAL DOCUMENTATION
- DESIGN MANAGEMENT AUDITS
- SW SPECIFICATIONS
- SW DEVELOPMENT PLAN

MSI 2 CONFIGURATION MANAGEMENT

- SELECTION OF CPCIs
- CM PLANS
- IDENTIFICATION OF SW
- BASELINE MANAGEMENT
- INTERFACE CONTROL
- SW LIBRARIES
- DOCUMENT MAINTENANCE/STATUS
- CONFIGURATION REVIEWS

MSI 3 TEST MANAGEMENT

- TEST PLANS, PROCEDURES, REPORTS
- TESTING AND ANALYSIS
- TEST SOFTWARE VALIDATION
- TEST MANAGEMENT AUDITS
- SW CORRECTIVE ACTION

EVALUATION SYSTEM

- MANAGEMENT SYSTEM REVIEW
  - SURVEY
  - COMPREHENSIVE EVALUATION
- SIGNIFICANT MANAGEMENT CONCERNS
  - LIBRARY CONTROL (NONDELIVERABLE)
  - DOCUMENTING FIRMWARE
  - TEST AND ENGINEERING SUPPORT SOFTWARE
  - DESIGN AND PROGRAMMING STANDARDS FOR NONDELIVERABLE SOFTWARE
- CMSE CRITERIA REVIEW
  - AFCMD DETACHMENTS
  - COMPANIES
- REACTION
  - TEST SOFTWARE NEEDING ATTENTION
  - INTEGRATION OF HARDWARE/ SOFTWARE EVALUATIONS
  - DEFINING THE CRITICALITY OF SOFTWARE
  - EVALUATING FIRMWARE DEVELOPMENT

BUYING AGENCY SUPPORT ACTIVITIES

- OVERVIEW
  - AFPROs PERFORM CONTRACT ADMINISTRATION IAW DEFENSE ACQUISITION REGULATION (DAR 1-406)
  - AFPROs SUPPORT BUYING AGENCIES BY MOA
- PROPOSED TASK LISTINGS
  - EXPLICIT DEFINITION OF AFPRO TASKS
  - DETAIL TASKS TO APPROPRIATE LEVEL
  - USE TO DEFINE PERSONNEL TYPE AND SKILL NEEDS
  - MINIMIZE OVERLAP WITH SPO

SAMPLE EN/QA AFPRO INVOLVEMENT

DESIGN PHASE	CODE UNIT TEST	INTEGRATION	FORMAL TESTS	FCA/PCA
- PREPARATION OF SPECIFICATIONS	* AUDIT DOCUMENTS	WITNESS INTERNAL DEMONSTRATIONS	ASSIST SPO	ASSIST SPO
- REVIEW READINESS	DETAIL SCHEDULE REVIEWS	*- WITNESS DRY RUNS	* MONITOR WITNESS RETESTS	* REVIEW CONTRACTORS READINESS
PROJECT INTERNAL PROCEDURE REVIEW	WITNESS SELECTED TESTS	- SCHEDULE STATUS		
- INTERFACE DEFINITION	- REVIEW CRITICAL CODE			
REVIEW STANDARDS AND CONVENTIONS				

*CONFIGURATION CONTROL BOARD

*PROBLEM IDENTIFICATION & ASSESSMENT

*CONTRACTOR/SPO COMMUNICATIONS

*HIGH PRIORITY TASKS

PLANNING CONSIDERATIONS

- NEAR TERM OBJECTIVES
  - ESTABLISH COMPUTER RESOURCE STAFF OFFICE
  - PUBLISH SOFTWARE CMSE
  - DEVELOP GUIDEBOOKS
    - SAMPLE ADEQUACY CRITERIA
    - RECOMMENDED DIRECT SUPPORT TASKS
  - CONDUCT BASIC SOFTWARE QA TRAINING
- FUTURE PLANNING OBJECTIVES
  - CONTRACT REVIEWS
  - IMPROVED MOAs
  - INTERAGENCY TRAINING PROGRAMS

AIR FORCE MANAGEMENT

- IMPROVE USAF'S MANAGEMENT OF WEAPON SYSTEM EMBEDDED COMPUTERS

PROBLEMS

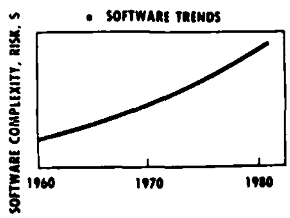
- GIVEN RECENT TRENDS, ESCALATING SOFTWARE SUPPORT COSTS WILL COMPROMISE USAF'S MISSION READINESS.
- LONG DEVELOPMENT TIMES.
- OPERATIONAL PHASE SOFTWARE PROBLEMS--STILL GENERALLY POOR.
- AN INCREASINGLY MORE CAPABLE AND TECHNICALLY SOPHISTICATED ENEMY.

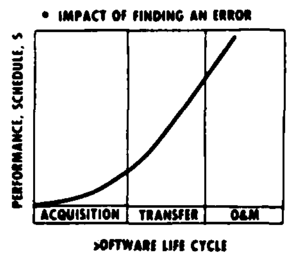
CAUSE

- A LIMITED BUDGET AND CONTINUED BUDGET REDUCTION PRESSURES
- NEW TECHNOLOGY STILL EVOLVING
- LACK OF STANDARDIZATION IN DEVELOPMENT OF HARDWARE AND SOFTWARE
- PROLIFERATION OF EMBEDDED COMPUTERS & LANGUAGES IN NEW SYSTEMS
- DISAGREEMENT AS TO WHAT TYPE OF SUPPORT FACILITY SHOULD BE BUILT AND WHO SHOULD OWN IT IN THE C^3 AREA
- A HISTORY OF CHANGE OVER THE LIFE CYCLE OF A WEAPON SYSTEM

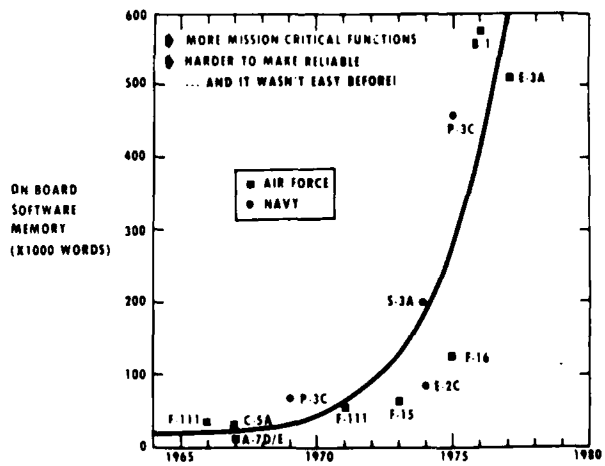
THE SOFTWARE PROBLEM

- COST VERSUS COMPLEXITY
- 9-1 OVER HARDWARE BY 1985
- CONTRACTOR'S ASSESSMENT





GROWTH IN DOD SOFTWARE DEMAND MEANS



WHAT IS NEEDED

- DISCIPLINED SYSTEM DEVELOPMENT ENVIRONMENT.
- MORE EMPHASIS ON STANDARDIZING LANGUAGE AND SUPPORT SYSTEM.
- MORE INTERACTION NEEDED BETWEEN DEVELOPER, OPERATOR AND MAINTAINER.

CORE CONCEPT

Major Jim Riley, ALD

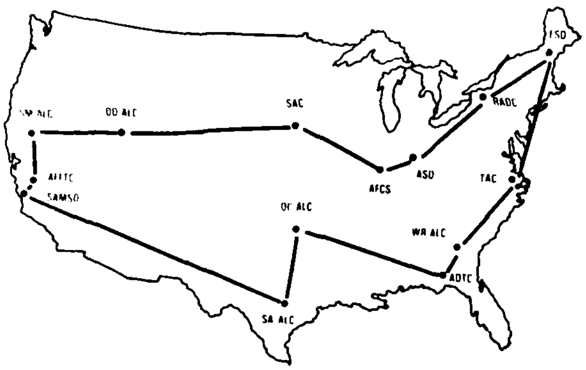
AN APPROACH

CORE CONCEPT

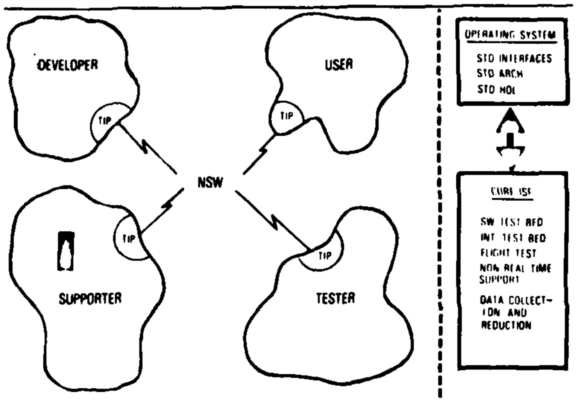
STANDARD DEVELOPMENT, TEST, AND SUPPORT CAPABILITY BASED ON STANDARD WEAPON SYSTEM HARDWARE AND SOFTWARE INTERFACES.

USE A CONCEPT LIKE NSW BASED ON DARPA NET TO LINK THE USER, DEVELOPER, TESTER, AND SUPPORTER.

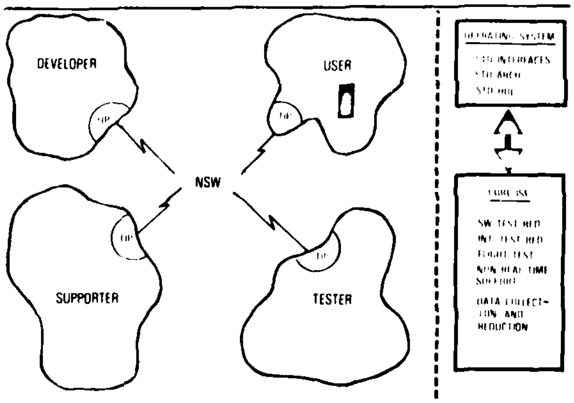
THE NATIONAL SOFTWARE WORKS (NSW)



CORE CONEPT



CORE CONCEPT



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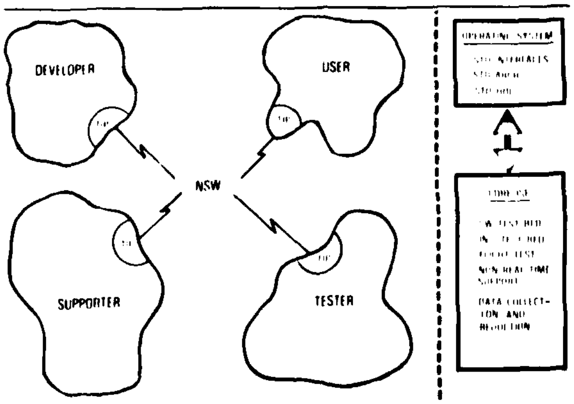

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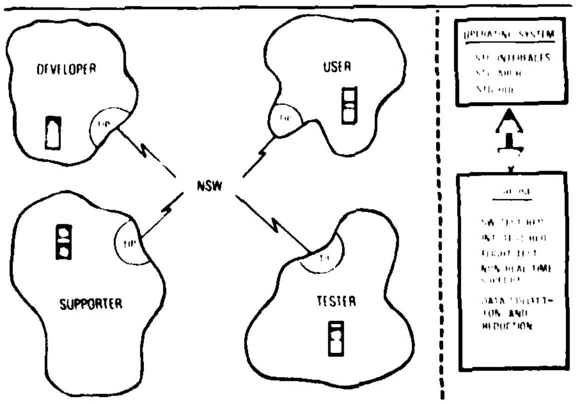

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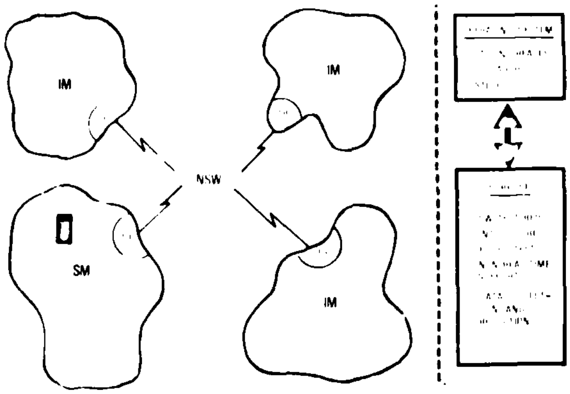
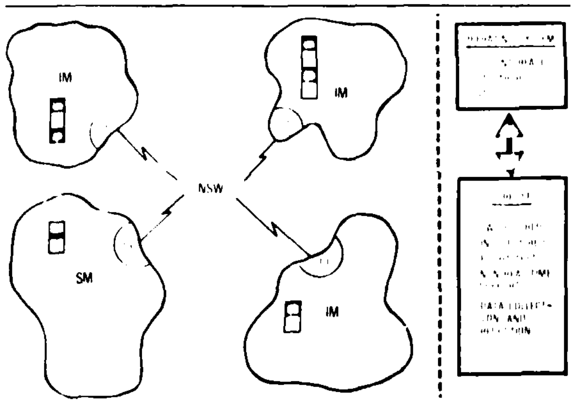


CORE CONCEPT



POTENTIAL BENEFITS

- CONTROL COSTS
- POTENTIALLY SHORTENED DEVELOPMENT TIMES
- IMPROVED S/W RELIABILITY I.E. FEWER ERRORS
- IMPROVED RESPONSE TO CHANGE, I.E., EW CHANGES (QRC)
- EXPEDITE MANAGEMENT DECISION PROCESS

BUT.....

- PROBLEMS WITH GFE OF HARDWARE/SOFTWARE?
- STIFLE COMPETITION?
- STIFLE TECHNOLOGY?
- LITTLE ORGANIC SOFTWARE SUPPORT IN SPACE PROGRAMS

SOLUTIONS

- GOOD MANAGEMENT
  - STANDARDIZE ONLY WHERE IT MAKES SENSE
    - B-52 OAS EXAMPLE
  - MATURE STANDARDS
  - STEPWISE INFUSION OF NEW TECHNOLOGY
  - STANDARDIZE AT INTERFACE LEVEL
- APPLICABILITY TO SPACE PROGRAMS
  - SD SHOULD INVESTIGATE
  - REQUIRE LARGE SCALE CONTRACTOR INPUT

SOFTWARE QUALITY ASSURANCE

R.L. Evans
Command, Control, Comm. Company

GUIDEBOOKS WRITTEN
FOR SERVICES BY
CONTRACTORS-
DEFINED "ACTIONS" ASD/ESD/SAMSO
WERE TO TAKE RELATIVE TO SWQA

SOFTWARE QUALITY ASSURANCE PRESENTATION TO THE 1980 CONFERENCE AND WORKSHOP ON MISSION ASSURANCE

WHAT IS THIS
THING CALLED
SOFTWARE QUALITY ASSURANCE

PROLIFERATION OF MIL-SPEC'S

MIL-S-52779(AD)
MIL-S-52779A
AFR 800-14
MIL-STD-1679
MIL-STD-1644

SCHOOLS ARE GIVING COURSES IN SWQA

1) WHAT DO THEY TEACH?
2) HOW DOES IT RELATE TO HARDWARE/SYSTEM QA?
3) QA TOOLS DEVELOPMENT/IMPLEMENTATION?
4) COMPARISON BETWEEN HARDWARE/SOFTWARE?

ARE COMPANY STANDARDS REALISTIC AND BEING IMPLEMENTED OR ARE THEY STRICKLY P.R. ARE RFP'S/CONTRACTS REALISTIC RELATIVE TO SOFTWARE QA PROVISIONS - WHAT IS SWQA OTHER THAN AS DEFINED IN MIL-S-S-52779, MIL-STD-1679 & -1644 AND WHAT DOES IT MEAN TO A 1 MILLION, 10M, 20M, $ CONTRACT.

MOST SWQA ACTIVITIES HAVE BEEN DISCUSSED AND REDISCUSSED - BASED ON THESE DISCUSSIONS AND WORKSHOP'S WHAT HAS HAPPENED? ARE SWQA ACTIVITIES HAPPENING? ARE SWQA PLANS BEING IMPLEMENTED? AUDITED? WHAT ARE RESULTS OF AUDITS? HAVE CORRECTIVE ACTION SYSTEMS BEEN DEVELOPED? ARE LESSONS LEARNED TRANSPORTED TO NEW SW SYSTEM DEVELOPMENTS?

RECOMMENDATIONS -

NEED TO ESTABLISH SWQA WITHIN THE QA ACTIVITIES - BOTH HARDWARE/SOFTWARE FOLKS CAN LEARN FROM EACH OTHER - NEED TO ESTABLISH A "FEEDBACK" SYSTEM FOR SOFTWARE -

o QA FIND DEFECTS EARLY - FEEDBACK OF THE NECESSARY INFORMATION WHICH WILL PREVENT PRODUCTION SUBSTANDARD PRODUCT.

o QA COMBINED EFFORT. HAVE AUDIT TEAM DOUBLE CHECK THE RESULTS FOUND DURING INSPECTION.

o ESTABLISH COMMUNICATIONS NETWORK - HAVE SYSTEM WHICH WILL GUIDE QA PERSONNEL THROUGH THE PROBLEM SOLVING PROCESS.

o PUBLISH FINDINGS - THE RESULTS OF SWQA EFFORTS OFFER ADDITIONAL GUIDANCE TO TOP LEVEL MANAGEMENT; CHART FINDINGS; PUBLISH.

CONCLUSION:

QUALITY ASSURANCE ORGANIZATION
MUST TAKE RESPONSIBILITY
FOR ALL QA ACTIVITIES INCLUDING
SOFTWARE.

QA MUST ESTABLISH AUDIT ACTIVITIES
TO ASSURE STANDARDS ARE BEING
FOLLOWED.

QA PERSONNEL MUST BE TRAINED TO
UNDERSTAND THE SW PRODUCTION PROCESS
AND "QA" TOOLS WHICH CAN/WILL BE USED.

INDEPENDENT VERIFICATION AND VALIDATION TESTING OF THE SPACE SHUTTLE PRIMARY FLIGHT SOFTWARE SYSTEM

A.J. Macina
International Business Machines Corp.

ABSTRACT

The onboard Space Shuttle flight software system, developed under contract to NASA, is responsible for virtually all onboard functions related to vehicle guidance, navigation, and flight control. In addition, it performs numerous vehicle systems management and monitoring functions as well as providing vehicle-to-crew and vehicle-to-ground interfaces. Unlike many commercial and aerospace software systems, the Shuttle software cannot be incrementally tested under operational conditions before delivery to the customer. The software for the Shuttle's first flight will not undergo suborbital or unmanned test flights. Instead, the integrated system will be expected to operate flawlessly the first time it is placed in an operational environment. Since the software package is an integral and critical part of the Shuttle system, a development and testing approach has been employed which addresses the unique Shuttle requirements, namely, to provide software which meets the letter of the contractual requirements, performs in accordance with Shuttle operational requirements, and is "error-free." The organization charged with the development and delivery of this complex system differs from other software development groups in that it contains a totally independent line-organization whose purpose is to provide final verification before delivery, that is, prove the system is "error-free" and therefore ready for flight. The verification organization operates in parallel to the development groups but maintains complete independence. During the development phase of the software contract the Verification group gains familiarization with the detailed requirements and the evolving design, and finalizes a comprehensive test plan to be approved by the customer. This test plan is approached with the attitude that the software is essentially untested. Following completion of the development phase, the software is placed under configuration control by the Verification group. It is then subjected to an extensive series of code inspections, detailed logic tests and overall system performance tests executed on a simulator which utilizes actual Shuttle computer hardware. All discrepancies are documented, corrected, and the area of the software which was altered by the correction is re-verified. At the completion of the verification testing, the customer reviews the entire test program and selected test results. The customer then assumes responsibility for configuration control of the software. Shuttle experience to date has deviated somewhat from the strict serial approach of development, verification, and delivery. Experience has shown that it is advantageous to release software for use in NASA trainers and integration laboratories at the same time it is delivered for verification. This approach adds "shelf-life" to the software without the expense of additional "elapsed-time." The approach also fosters early identification of discrepancies and needed requirements changes.

INDEPENDENT VERIFICATION AND VALIDATION TESTING OF THE SPACE SHUTTLE PRIMARY FLIGHT SOFTWARE SYSTEM

1. INTRODUCTION

The development and verification of the Shuttle onboard Primary Avionics Software System (PASS) has posed unique challenges associated with few other aerospace or commercial software systems. These challenges stem from its size and complexity, its criticality to completion of the Shuttle mission, and from the fact that it is only one of many components of an overwhelmingly complex state-of-the-art Space Transportation System (STS).

With respect to size and complexity, the software being readied for the first orbital flight test (STS-1) of the Shuttle is actually eight separately executable programs or memory configurations sharing a common operating system. These programs are stored on a mass memory tape device and are loaded into the onboard computers on crew request (see Figure 1). One of the eight performs all functions necessary to the launch, ascent, and orbit insertion phases of the mission. Two others provide software to be used during on-orbit operations and include both navigation and control functions as well as system monitoring and management functions. Another memory configuration performs all functions necessary to the de-orbit, entry, and landing mission phases. The remaining four are designed to perform critical pre-launch and on-orbit vehicle checkout procedures. In all, these eight programs, including the software operating system, comprise approximately one-half million 32-bit words of data and executable instructions. All Shuttle applications software modules and a large part of the operating system included in these memory configurations are implemented in the HAL/S high order language. The language and associated compiler, specifically developed for aerospace applications, are scientifically oriented and especially suited to realtime systems.

The criticality of the software to the Shuttle is emphasized by its numerous interfaces with other vehicle subsystems. There are few functions integral to the Shuttle operation for which the software does not perform some type of computational service. Specifically, the onboard software is responsible for the guidance, navigation, and flight control functions performed during all flight phases. This includes both the gathering of environment and sensor input data and the issuing of commands to the vehicle effectors (engines, aerosurfaces, etc.). The software also handles all vehicle/ground interface functions pre-launch through landing via a direct launch data bus (ground) or telemetry (in flight). In addition, it provides many crew/subsystem interfaces. Other software functions include the management and monitoring of onboard systems, fault detection and annunciation, and pre-flight and pre-entry checkout and safing procedures.

The number and size of the services performed by the onboard software are not the only factors contributing to its complexity. The requirement for redundancy to achieve reliability has also been a factor. To obtain the required "Fail-operational/Fail-safe" reliability, the software in certain critical flight phases must execute redundantly in multiple computers. For example, during the STS-1 mission the software for the Ascent and Entry phases will execute redundantly in four of the five IBM System/4 Pi Model AP-101 General Purpose Computers (GPCs), the fifth computer being reserved for the Backup Flight System (BFS) (see Figure 2). To achieve this redundancy, an intercomputer synchronization scheme which guarantees identical inputs and outputs from the redundant computers had to be developed. The software needed to support this redundancy requirement is an integral part of the operating system architecture. It provides such functions as computer synchronization at rates up to 330 times per second and control of input data to assure that all computers receive identical information from redundant sensors whether or not hardware failures have occurred. A detailed discussion of the Shuttle redundant computer operation can be found in Reference 1.

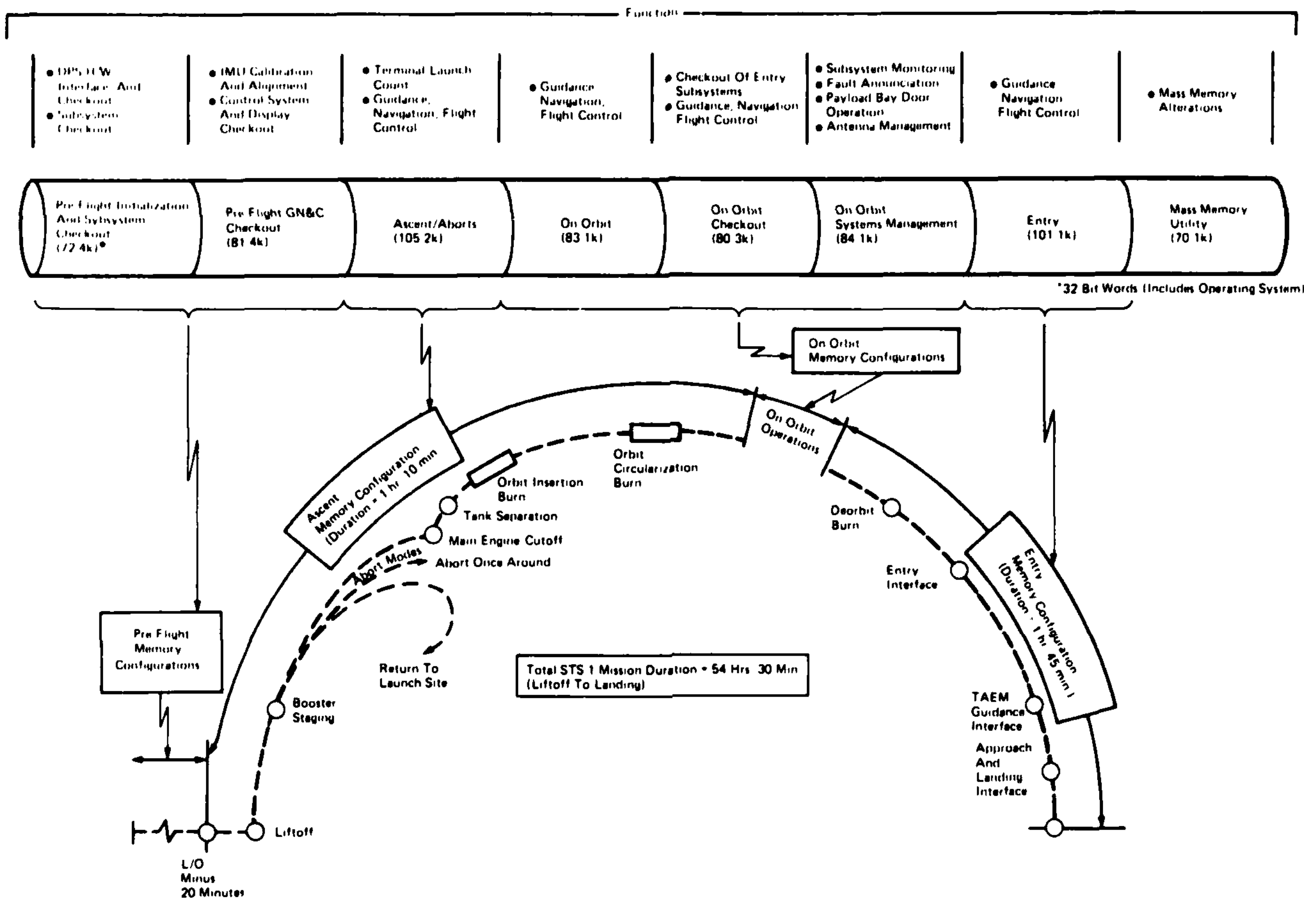


Figure 1. Shuttle Mission Profile and Software Memory Configurations

2. SOFTWARE DEVELOPMENT AND TEST ORGANIZATION

Goals and Objectives

The organizational structure responsible for the development and test of the Shuttle software evolved from previous space software development programs including Apollo and Skylab. The most beneficial experience, however, was gained during the Approach and Landing Test (ALT) phase of the Shuttle program in which a small portion of the onboard software was developed, tested, and flown. Although this system was considerably smaller and the flight environment benign in comparison to the STS-1 mission, valuable software design, test, and managerial experience directly applicable to the STS-1 activity was gained.

The primary objectives of the STS-1 software organization can be summarized in three key points. The first and most obvious is to:

- Develop software which **adheres to the letter of the customer's requirements.**

This refers to formal requirements documentation. Secondly,

- To assure that the software performs in accordance with the **Customer's operational expectations** for both nominal and off-nominal conditions.

This refers to operational requirements explicitly or implicitly identified in crew procedures, operational mission profiles, etc. And finally,

- To provide software which is **"error-free."**

The first two goals are easily quantifiable since specific and testing plans can be implemented to achieve them. For instance, specific test scenarios can be developed to cover all documented software requirements and a one-to-one mapping maintained and reported. This has been done for the STS-1 software and will be discussed in Section 5.

The third goal of producing error-free software is a more nebulous objective when applied to complex systems and, as experience has shown, can only be asymptotically approached. How well a software development and test organization does in achieving this goal depends on how effectively it is structured to address the following areas:

- Early identification and application of programming standards and techniques with subsequent checks on the fidelity with which these have been followed.
- Establishment of tests, audits, and code inspections not specifically driven by customer requirements

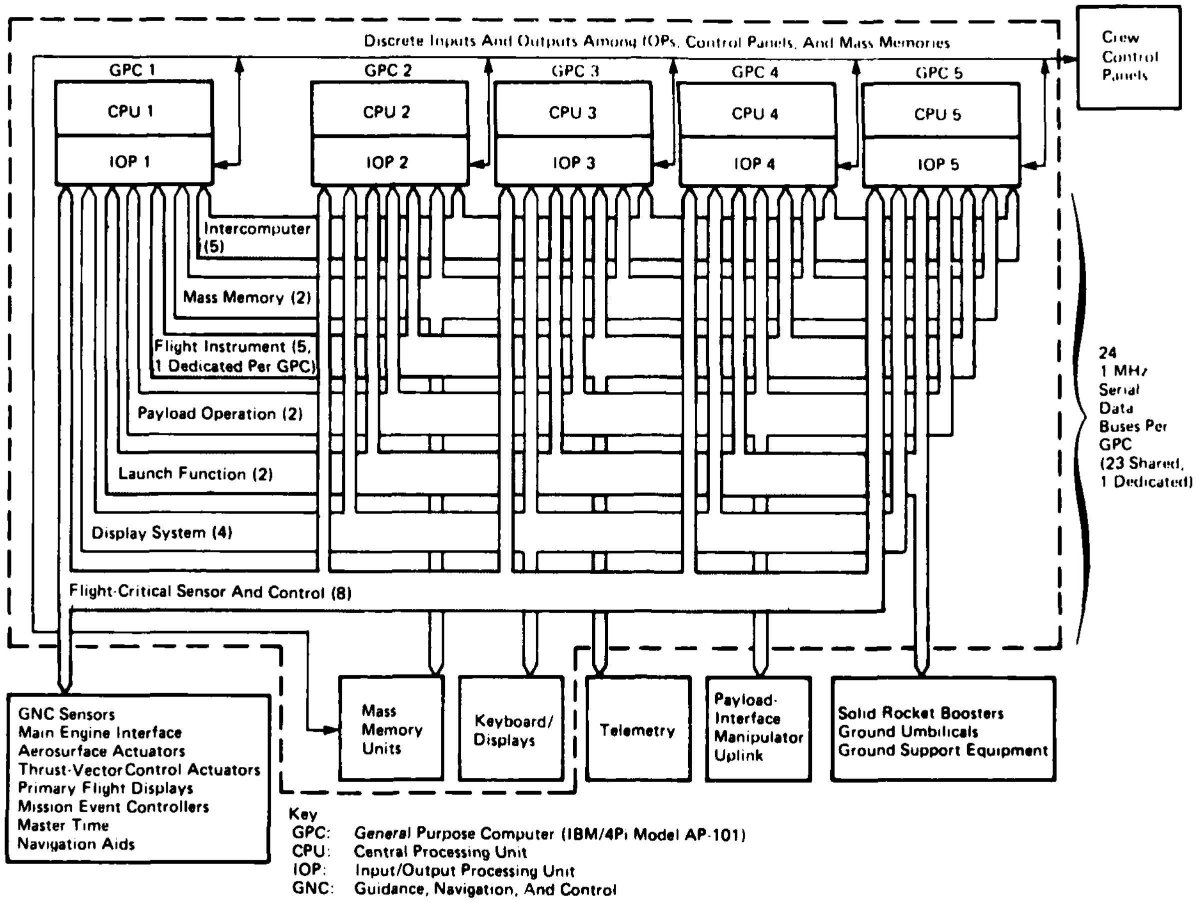


Figure 2. Space Shuttle Data Processing System

but necessary to prove the design error-free. Specific examples of these will be mentioned later during the discussion of detailed/functional verification in Section 5.

- Early definition of requirements for the simulation test bed(s) and other support software accompanied by a thorough test plan and subsequent configuration control.
- Configuration control of the incremental build and integration of the evolving software system.
- Configuration control of the implementation and retest of the software changes resulting from requirements upgrades and discrepancy corrections.

Functional Areas

The organization chosen to address each of these key items is divided into five functional areas. Each represents a line department although all are not equal in size or position within the organizational hierarchy. They are:

- Requirements Analysis and System Architecture
- Software Development
- System Integration and Build
- Independent Verification
- Customer Support and Field Test.

Software Design, Development, and Integration

The first three functions, found in most software organizations, are responsible for the design, implementation, integration, and module-through-system-level test of the software. The Requirements Analysis group, a "front-end" organization, oriented toward applications software, is made up of engineers and programming specialists familiar with avionics systems. Their participation started with involvement in the early formulation of the software requirements by NASA and the prime contractor, Rockwell International. Their role was to assess the feasibility of implementing the requirements into the data processing hardware and software. A second objective was to gain an in-depth understanding of the chosen avionics design to guide their subsequent system-level software design activities. This understanding of both the avionics design and the software structure also proved invaluable to requirements analysts in their later role as advisors to the programmers implementing the detailed software design.

The System Architecture organization performs a role similar to the Requirements Analysis group with their efforts primarily

directed toward the operating system software. In addition, their responsibilities included the sizing and measurement of the evolving software package (CPU utilization, memory size, timing measurements).

Shuttle software development is divided into two major organizations, one responsible for the operating system and associated user interface software, and the second responsible for the "applications" software (e.g., navigation software, flight control software, etc.). These organizations, assisted by the requirements analysts and system architecture personnel, design and code the software at the module or subroutine level. They also perform initial integration by coupling individual modules with an executive structure to produce overall subsystems such as the Guidance, Navigation, and Flight Control Software. Testing is performed at each level of development from the module level using driver programs, through the initial integration level.

The final integration of applications programs with the operating system is performed by the System Integration group. It is this group's responsibility to collect new or updated software modules from the development organizations, compile or assemble them, and use the resulting object code to update a master software system library. This master system is then link-edited and passed through a mass memory build program which converts it to a form which can be used to load a Shuttle onboard mass memory tape unit. The combined Integration and Development organizations perform additional system level tests after the final systems have been built. These include nominal flight simulations in a multicomputer environment as well as hardware/software interface tests.

As a part of their development and integration responsibilities, these three organizations define, apply, and enforce programming standards and techniques. They also maintain configuration control during all levels of design, coding, integration, and testing. This control pertains not only to the software package but also associated documentation such as requirements baselines, design descriptions, discrepancy tracking, and integration and system build documentation.

Independent Verification

Independent Verification, which will be discussed at length in Section 5, is a separate line organization with the ultimate responsibility of assuring that the software is error-free. The Verification group maintains an equal status with the Software Development organization, and derives its authority by remaining completely independent with respect to management and personnel. The Verification organization for the Shuttle PASS is shown in Figure 3.

The philosophy of the Verification group is based on the premise that the software is untested when received. This is a key factor in the development of their test plan. Because their role is essentially that of a pseudo-customer, they maintain an adversary relationship with the Development groups. Verification receives the software at the end of the design, development, and integration cycle and subsequently subjects it to a complete verification/validation program. The ideal timeline for the development, verification, and delivery of the software will be discussed in Section 3.

Customer Support and Field Test

The Customer Support and Field Test activity ideally begins after the formal Verification testing is complete and the system has been inspected and accepted by the customer. In reality, this activity occurs in parallel with Verification for reasons which will be discussed later. This organization provides a number of services to software users at customer test sites (simulators) and on the actual Shuttle vehicle. These include: installation and checkout of the newly released software; problem analysis, troubleshooting and implementation of temporary solutions; customer education and customer/software organization liaison; test site unique software alterations; customer test program support; crew training program support; mission support.

3. SOFTWARE DEVELOPMENT LIFE CYCLE

Figure 4 describes a typical software development and test cycle. The chart presents a simplified and somewhat idealized

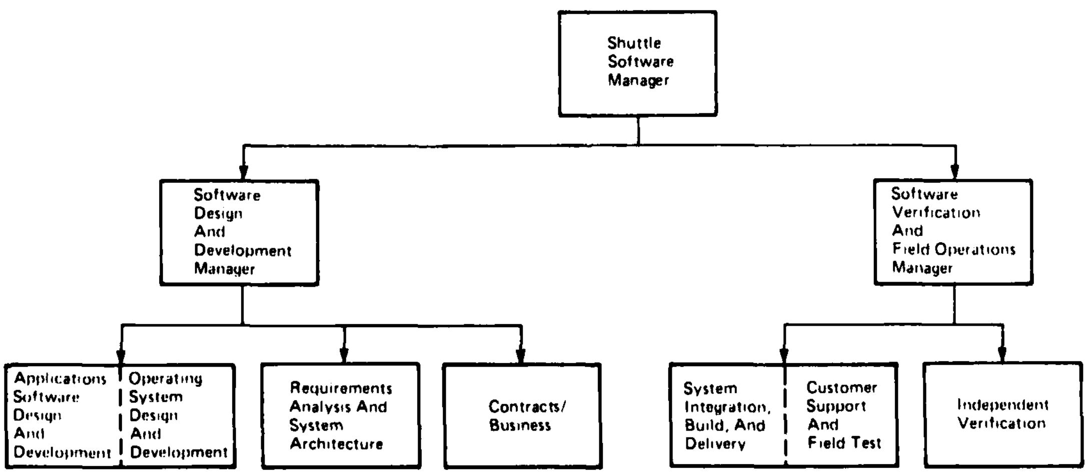


Figure 3. Shuttle Software Organization

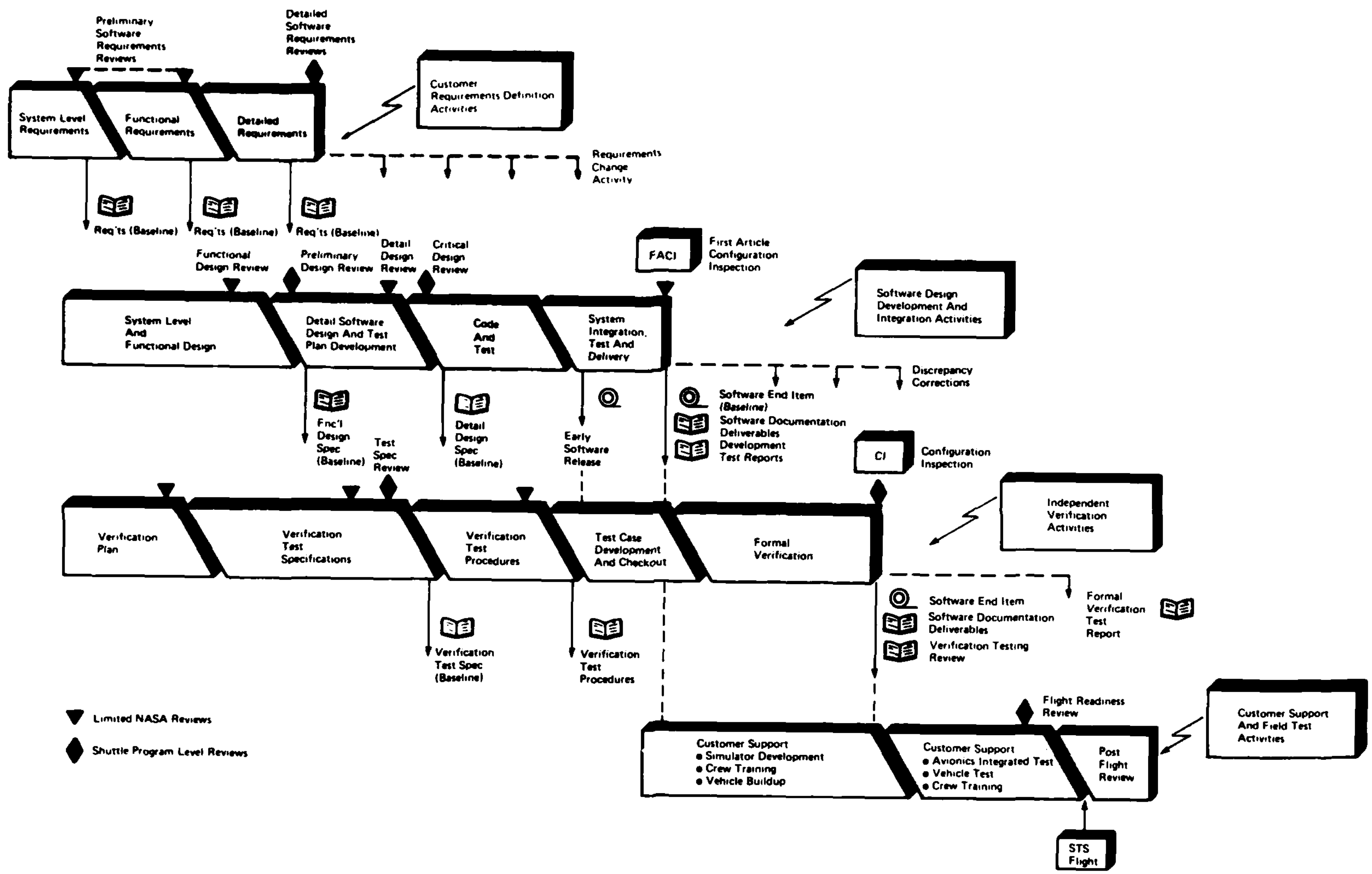


Figure 4. Software Development Life Cycle

view of the cycle, describing customer and organizational interfaces as well as the flow of design, development, test, delivery, and maintenance. In general, STS-1 experience has shown the flow to be valid. Variations have been associated either with the phasing of activities, or with the number of times each was performed. The relationship between the current STS-1 software delivery schedule and this ideal flow will be discussed in Section 6, entitled "Field Test - Early Customer Involvement."

Figure 4 shows the three phases of the requirements definition process. System-level requirements address the overall system architecture, including the operating system and user interface software. Functional level requirements describe high-level applications software interfaces, general capabilities, and timing requirements. Examples include guidance, navigation, and flight control software functional requirements, and the vehicle checkout software functional requirements. Detailed requirements define equations, algorithms, initialization data, and formats for all areas described in the functional requirements. Examples are redundancy management, ascent navigation, telemetry uplink, etc. Definition of these phased software requirements was not unilateral but was performed by design teams with representation from all areas of the Shuttle engineering community, both NASA and contractors. IBM participation included representatives from both the software design and development organization and the Verification group. Final baselining of the requirements documents was the responsibility of the NASA Space Shuttle Orbiter Project Office.

Both the software development and verification activities are initiated early in the requirements definition period. The development activity progresses through a high-level functional design to a detailed design and test planning phase. Contractual documentation for each phase is again baselined by the NASA Space Shuttle Orbiter Project Office before proceeding to the coding and integration of the software. The mainline development activity culminates with the First Article Configuration Inspection (FACI) where the integrated software package and all supporting documentation is delivered to the Verification organization. At this point the software may also be made available to the customer for use in simulator development, crew training, and early vehicle build-up activities.

Prior to the FACI, responsibility for configuration control of the evolving software rests with the Software Development and Integration organization. Following the FACI, this responsibility is assumed by the Verification group. Also at this point Development and Integration assume a support role, implementing requirements changes, correcting software discrepancies, and providing updated software releases.

As mentioned, Verification activities start early in the requirements definition phase. A test plan is first developed defining the organization, schedule templates and deliverables. This is followed by development of Verification test specifications, which are high-level descriptions of the proposed testing based on the software requirements. These are reviewed and approved by NASA. Test procedures which consider both the requirements and the software design are then developed. These are detailed test descriptions which, in turn, can be used to build flight simulations and test scenarios. Ideally, all Verification test cases and simulations are executed and thoroughly checked out before the FACI using the early software release. Formal Verification then commences with additional planned releases of the software to incorporate changes. Verification ends at the Configuration Inspection (CI) with a formal delivery of the software to NASA and a review of Verification testing by the Space Shuttle Orbiter Project Office.

Following the CI, the software, now under NASA configuration control, is delivered for integration with other avionics subsystems. Subsequent avionics integrated tests in both simulators and on the actual Shuttle vehicle are then performed by NASA-/Rockwell with the support of an IBM software maintenance organization. This testing culminates with a NASA Flight Readiness Review (FRR) at which all integrated Shuttle systems including the software are accepted for flight.

4. DESCRIPTION OF TEST FACILITIES

Shuttle program test requirements necessitate use of three facilities for verification of the Shuttle avionics system: the Software Development Laboratory (SDL), the Shuttle Avionics Integration Laboratory (SAIL), and the Flight Systems Laboratory (FSL). A fourth facility, the Shuttle Mission Simulator (SMS), although not specifically involved in testing the avionics system, does play a major role in exercising the integrated avionics design through its extensive crew training activities.

The Software Development Laboratory (SDL), located in Houston at the Johnson Space Center, is the primary facility for the development, integration, and verification of the primary onboard software system. It was developed and is maintained by the software contractor (IBM) under contract to NASA. Its capabilities will be discussed later in this section.

The Shuttle Avionics Integration Laboratory (SAIL), also located at the Johnson Space Center in Houston, is responsible for avionics system integration and hardware/software certification. It is primarily used by NASA and the Shuttle integration contractor (Rockwell) to support elements of their avionics verification plan. The SAIL was designed as a simulation laboratory where avionics hardware (or simulations of the hardware), flight software, flight procedures, and ground systems will be fully integrated and tested. The SAIL also provides realtime mission support and post-flight evaluation capabilities. Its integration and test role for STS-1 emphasizes the pre-launch, ascent, aborts and orbit insertion phases of the Shuttle mission.

The Flight Systems Laboratory (FSL), located at the Rockwell facility in Downey, California, has capabilities similar to those of the SAIL. Its role in the Shuttle program is also similar in that it is used by NASA and Rockwell to perform avionics system integration and verification for the on-orbit, de-orbit, entry and landing phases of the mission. Both the FSL and SAIL are full six-degree-of-freedom flight simulators with man-in-the-loop capability.

The Shuttle Mission Simulator (SMS) is NASA's primary training facility for Shuttle crews. Located at the Johnson Space Center in Houston, it provides a realistic environment for training crews in all mission phases from pre-launch through landing and rollout. For STS-1 training, the SMS consists of two simulators, both employing actual Shuttle data processing system hardware. One, the "moving-base" simulator, provides cockpit motion consistent with vehicle dynamics. The second is a "fixed-base" simulator. Both provide extensive visual displays in addi-

tion to a direct link to the Mission Control Center, also in Houston. Although not directly involved in software testing, the SMS does provide an invaluable benefit in this area. Its extensive program of crew training under off-nominal conditions tends to subject the software to a wide variety of stress situations. This provides added confidence in the performance and capabilities of the system.

The SDL Facility - The Software Test Bed

The SDL serves a dual role in the Shuttle program. The Primary Avionics Software System is both developed and verified in the SDL. Because of its dual role, the laboratory has been designed with capabilities to analyze, verify, maintain, and control Shuttle flight software. Additionally, the SDL is used to integrate all software elements into an orbiter mass memory load tape used to load the Shuttle mass memory tape unit.

The SDL provides six major functions with which to perform development, verification, and integration activities. These functions are: a program management facility; a mass memory build facility; a simulator; a post-processor; a documentation, analysis, and statistics system; and an array of pre-processors.

The Program Management Facility (PMF) provides the programs and control needed to build, maintain, and track program data and create deliverable systems. The mass memory build facility provides the utilities by which Shuttle software elements are mapped into the format required by the orbiter's mass memory units. The mass memory build also creates universal patch format (UPF) tapes used by all Shuttle test sites to update onboard mass memory units.

The pre-processors provided by the SDL convert data required for flight into form that can be used by the flight software. This data includes mission-dependent initialization data (I-LOADs), display formats, systems management measurement tolerances, and downlist telemetry data.

The documentation, analysis, and statistics system provides users with the data necessary to develop, analyze, and maintain the evolving software system.

The SDL simulator and post-processor functions provide the primary facility used in the development and verification of the software system. Three simulation modes are available. The Interpretative Computer Simulation mode (ICS) provides an emulation of the AP-101 flight computer and input/output processor execution of code. The Functional Simulation Mode (FSIM) allows execution of flight code using a functional representation of the operating system. The third (and by far the most extensively used) mode is the Flight Computer Mode (FC) which allows execution of the flight software in actual Shuttle data processing system hardware.

The FC mode of the SDL simulator is the only mode used during the Verification testing of the software. It provides a realistic closed-loop, six-degree-of-freedom simulation of the Shuttle operational environment and avionics hardware (see

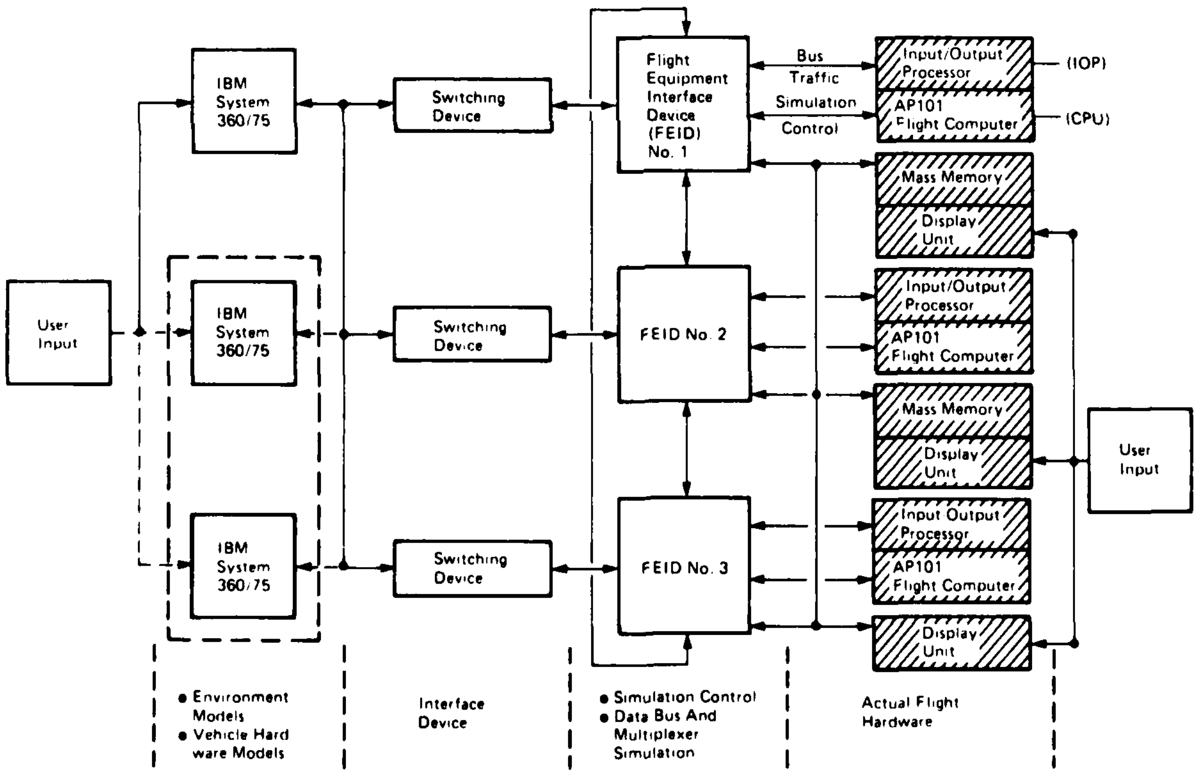


Figure 5. Software Development Lab - Flight Simulator

Figure 5). Available Shuttle hardware elements include the AP-101 flight computers and associated input/output processors, the crew Display Electronics Units (DEUs) and CRTs, and the onboard mass memory tape units. The user has the option to select software simulations of the DEU and mass memory hardware. All flight hardware is interfaced via a special-purpose Flight Equipment Interface Device (FEID). This device not only provides the hardware-to-hardware and hardware-to-host computer interface, but also the means by which the simulation is monitored and controlled.

The capabilities provided by the FEID allow the user to monitor and control the software execution at the flight software instruction or data location level. Users have the capability to "stop" a multi-flight computer simulation on time, event, or upon execution of a particular instruction or data location reference within the flight software. While the simulation is stopped, capabilities are available via direct memory access to alter or collect data from the flight computer main memory. Since the simulator is also stopped during this period, faults may also be introduced external to the flight computer in the simulated hardware or vehicle environment. Upon completion of the faulting or data collection activity, the simulation can be restarted without loss of continuity in instruction execution or I/O. This ability to stop on instruction and access or alter the contents of the flight computer without affecting the simulation is a unique feature of the SDL and is not available in the SAIL, FSL, or SMS.

The major outputs of the simulator are log tapes which contain the flight software commands issued and the data received or transmitted. The log tapes also contain diagnostic data such as data snaps, dumps, or traces requested by the user. The SDL post-processor provides a data reduction and manipulation capability for the log tapes. Post-processor capabilities allow users to specify the subset of logged data to be processed, its format, special computations that are required, and whether a comparison should be made with other simulations.

Because of its singular role as the test bed for the Shuttle primary onboard software, validation of the SDL has always been a prime concern. Requirements for the facility were defined very early in the software program by future users from all IBM software organizations. These requirements were baselined, implemented, thoroughly tested, and placed under configuration control by NASA. New capabilities require NASA approval and are implemented and tested at the detailed and system levels by a dedicated development and maintenance group. Final validation comes with use of the facility by the various software test organizations. In particular, the Verification group subjects the SDL to a thorough validation prior to the FACI as part of their test case development and checkout activities (see Section 5). SDL versions selected for use in formal flight software testing are placed under strict configuration control by both NASA and the user organization. In order to minimize variations in the test bed, only those changes considered mandatory to the completion of the testing are incorporated.

5. INDEPENDENT VERIFICATION TESTING

The Software Verification group is an independent line organization with a test plan based on the premise that the software is totally untested when they receive it. Since it is in line to the delivery and acceptance of the software by the customer, the Verification group has the ultimate responsibility of proving that the system (1) meets the letter of the requirements, (2) will, as a system, perform in accordance with operational expectations, and (3) is error-free. As previously discussed, these are overall organizational goals but Verification must demonstrate them to the customer at the Configuration Inspection.

Types of Testing

Verification testing is divided into two major categories, detail/functional testing and performance or system-level testing. The detail/functional tests address the question of whether the software meets the letter of the requirements and is basically divided by software functional area, e.g., ascent guidance programs, entry navigation, etc. Performance or system testing is directed at how the system as a whole will perform in both nominal and off-nominal or stress situations. As a result, the performance verification is divided by mission phase, i.e., ascent/aborts, on-orbit, entry. The majority of Verification testing is performed in the Software Development Laboratory (SDL) using actual Shuttle data processing system hardware. A small amount of Verification testing is performed in other facilities such as the Shuttle Mission Simulator (SMS) and Shuttle Avionics Integration Laboratory (SAIL) in order to take advantage of their extensive flight hardware and crew interfaces. A prime objective in both types of Verification is to perform all testing on the total unaltered (or "unscarred") software system rather than a modified or partial system.

Figure 6 describes the Verification organization structure which is made up of three departments. One is responsible for the detail/functional testing of the operating system and the pre-flight and on-orbit checkout software. A second carries out the detail/functional testing of the guidance, navigation, and flight control functions for all mission phases. The third department is the performance test group.

Verification's organizational independence and its assumption that the software is untested when received have both been emphasized earlier. In addition, two other attitudes play a key role in the Verification group's approach to testing. Since verifiers are considered systems analysts and not just "testers", they are responsible for attempting to diagnose problems and propose solutions when possible. This expedites Software Development's analysis and correction of alleged software discrepancies. This responsibility, however, is tempered by the overriding directive that . . . "when in doubt—assume the software to be at fault." This is key to providing error-free software. A second attitude addresses the software requirements and can be simply stated as . . . "the requirements are not to be considered infallible." These attitudes and assumptions cast Verification in the role of the conscience of the project and foster a definite but healthy adversary relationship between the Verification group and the Software Development organizations.

Detail/Functional Testing

The "detail" part of detail/functional testing refers to the explicit verification of all documented customer requirements. This includes logic paths, algorithms, decision blocks, initialization constants, etc. To achieve this, test cases are defined to cover each paragraph or explicit item in the requirements documents. A data base mapping of test case to requirement paragraph is maintained and delivered to the customer.

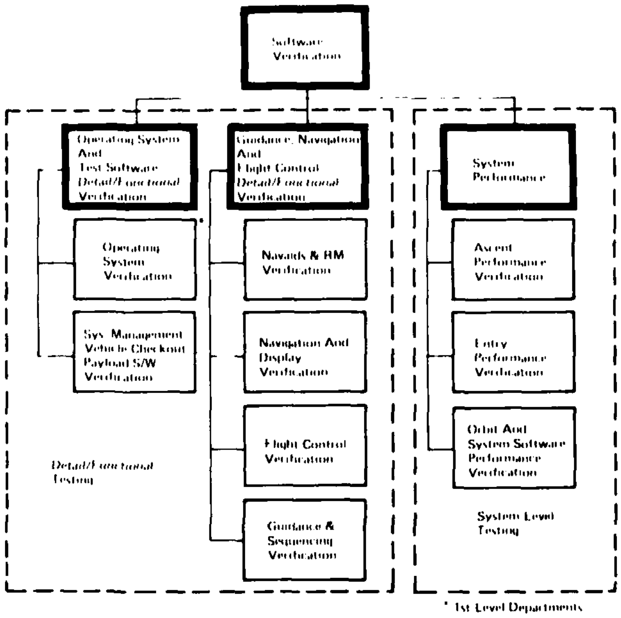


Figure 6. Verification Departmental Organization

Functional testing refers to the explicit verification of all software internal interfaces, external hardware interfaces, and software module and events sequencing. An example of the difference between detail and functional testing is shown in Figure 7. The figure depicts the software system as viewed by an analyst assigned the task of verifying the navigation software for a particular flight phase. Referring to the figure, the analyst would perform detailed verification of the internal paths by extracting and analyzing data from an SDL simulation at the entrance and exit of each path. Pass/fail or evaluation criteria used in the analysis is obtained from offline test programs, hand computations, or direct comparison to requirements. This provides assurance that the software adheres to the detailed requirements.

To satisfy the functional testing requirement, the navigation analyst also extracts data at points where the navigation software has input or output interfaces. Further, data is also collected external to the computer. Sensor input data which can affect navigation computations and output data such as that presented on the crew displays is also examined. This external data is correlated to that extracted at internal points in the software. It is obvious that this approach produces considerable overlap of testing when applied by all analysts. However, this overlap is considered an advantage when the objective is error-free software.

The SDL test cases used in the above detail/functional analysis involve the execution of the entire unaltered software system. The technique used is similar to that employed in flight simulators to avoid having to initialize each simulation at a dynamically quiescent point in the trajectory, e.g., at liftoff.

In the SDL a full ascent, orbit or entry simulation is executed and "reset" or "restart" points are selected at various times in the trajectory. At these points all data necessary to initialize the flight hardware and the host simulator is collected on a mass storage device. Detail/functional verifiers then construct short duration simulations, using these "reset" points to initialize their test in the region of interest. The required analysis data is then extracted via extensive SDL data collection facilities.

Execution of test cases is only one aspect of the responsibilities of the detail/functional analyst. Associated with each test case is a standardized checklist which must be filled out before the test case is considered completed. One item on this checklist is the code inspection of all software modules covered by the case. This "mental walk" through the software has proven to be especially fruitful in uncovering particularly subtle discrepancies.

Early Approach and Landing Test (ALT) software verification showed that detail testing against requirements and overlapping functional testing did not fully verify all aspects of the software. Another class of tests, called "common function tests", was required. In general, these are code surveys and audits, some of which are supported by data collected from simulations. Examples include:

- a review of the software to determine whether all divide operations are overtly protected against overflow conditions.
- verification that all data is initialized at memory reconfiguration.
- an audit of all telemetry data to be provided to the software (UPLINK), or to the ground by the software (DOWNLIST).
- a software review to verify that programming standards identified during the software design phase

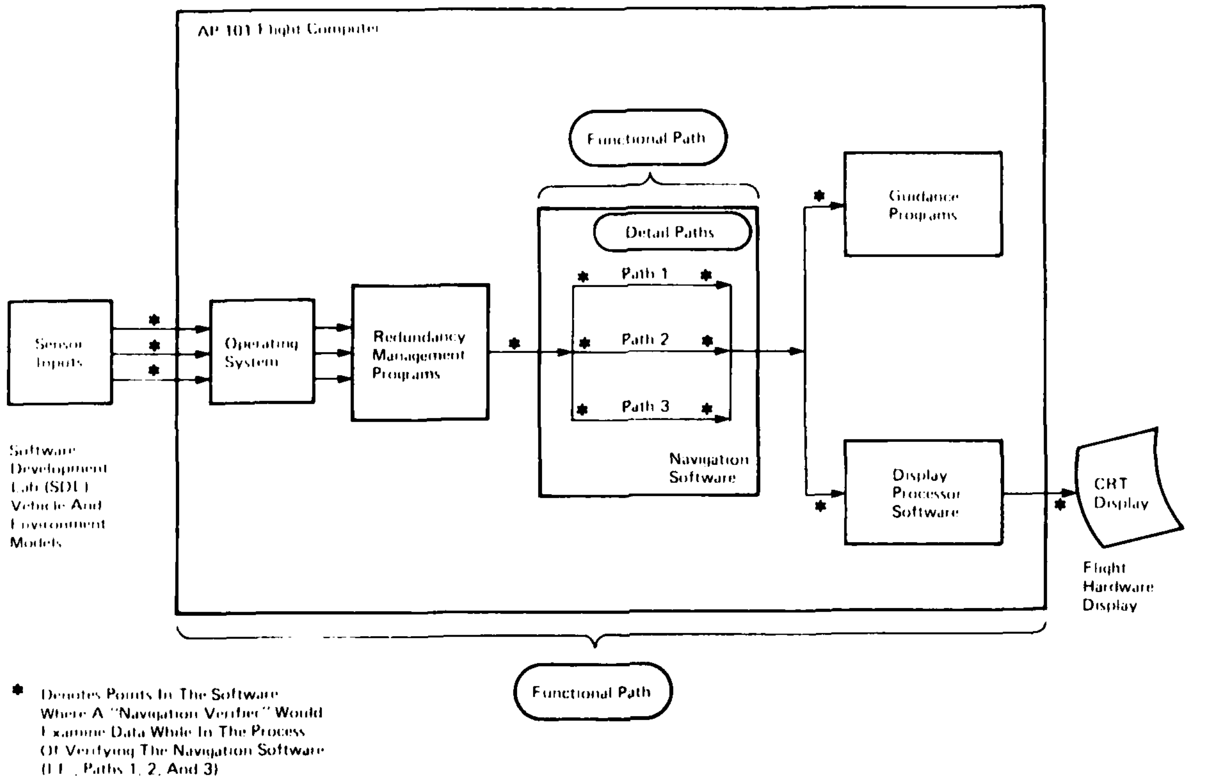


Figure 7. Example of Detail/Functional Verification

have been followed. This refers to the use of both the HAL/S language and the AP-101 assembler, and standards imposed to ensure intercomputer synchronization

The programming standards review is probably the most extensive survey performed on the software, involving 16 separate surveys which must be performed for the eight memory configurations

The size of the overall detail/functional verification effort involves just under 1000 separate test cases and code surveys. The STS-1 activity was initiated nearly three years ago and has involved approximately two-thirds of the total Verification work force.

Performance Testing - System-Level Tests

The purpose of performance testing is to exercise the total software system in a realistic operational environment and subject it to off-nominal stress situations. The off-nominal conditions introduced in the performance tests are of two types. The first are "reasonable" or expected failures and anomalies resulting from hardware malfunction, environment aberations, or user errors These are anomalies which the Shuttle has been designed to withstand. The second type of failure involves introduction of extreme or catastrophic conditions including low probability failures, and multiple or simultaneous failures which stress the software and/or the Shuttle system, at times to the breaking-point.

The test scenarios for the software performance cases are very similar to those used by the Shuttle integration contractor (Rockwell) to verify the integrated avionics system. They involve flight simulations of the various mission phases using actual Shuttle data processing system hardware. The software cases, numbering about 100 separate simulations, are for the most part executed in the Software Development Laboratory. A small number are executed in the Shuttle Mission Simulator to take advantage of its crewman-in-the-loop capability. All simulations are developed using published nominal and malfunction crew procedures.

Since the performance cases in their entirety were selected to be a part of the CI Acceptance Tests (see subsection entitled "Test Documentation and Review"), they have received extensive attention from the NASA Project Office and the general avionics community. The content and timing of the failures introduced in each of the 100 cases, as well as the basic timelines and data collected for analysis, have been the subject of review for the past two and one-half years. After being baselined in mid-1978, they were placed under NASA configuration control. In addition, periodic coordination meetings were held to encourage continued community involvement during the development and early execution of the cases. These Test Coordination Team meetings, chaired by NASA, involved representatives from all interested NASA and contractor organizations. The objective of the meetings was to promote continued review of test procedures, initial case results and analysis techniques in light of changing software requirements and updated mission timelines.

The performance cases themselves fall into two general categories: guidance, navigation, and flight control (GN&C) cases;

and, system services or operating system cases. The first, the GN&C performance cases, make up about 80% of the tests. These include nominal simulations for all flight phases but are for the most part failure oriented. Also included are "end-to-end" (pre-launch through landing) simulations for the nominal mission and aborts. Anomalies introduced in the GN&C cases are of three types:

- failures or anomalies originating external to the data processing systems, that is, within other avionics hardware or vehicle hardware. Examples include NAVAID failures, engine failures, hydraulic failures, etc.
- environmental stress, including vehicle state offsets, winds, and atmospheric variations.
- crew-induced stress such as early or late moding of the software and delayed switch settings.

The second type of performance case, the system services stress test, introduces severe single or multiple data processing system or vehicle system failures. The failures are designed to stress the operating system software in several critical areas, including input/output data processing, multi-computer redundancy management (i.e., computer synchronization), and CPU utilization performance.

The evaluation criteria used in the analysis of performance cases generally consist of two major activities. The first is a performance analysis of the vehicle/avionics system. This is refered to as a GN&C analysis and includes several components. One is an engineering analysis of the actual response of the system vs. the expected response. A second compares the vehicle's performance against documented inflight/mission constraints. These include reference flight profiles and other pass/fail criteria used by the avionics integration contractor in their certification program. A third type of GN&C analysis involves the plot-on-plot comparison of case results against identical cases executed in other simulations (called "Comparison Tests"). This analysis not only serves to identify problems in the software design but has also been key in providing confidence in the SDL simulator. A final GN&C analysis is used in the evaluation of failure cases and involves a plot-on-plot comparison of the case against an identical simulation with the failure removed.

In addition to a GN&C analysis, all performance cases are analyzed for software operating system performance. Special purpose diagnostic data collection performed on each case determines whether the operating system has detected any software errors during the simulation. General system measurements are also collected on most performance cases. These include measurement of CPU utilization and timing constraints such as transport lags. These measurements are used to demonstrate adherence to numerous system software timing requirements.

Software Verification Activities Prior to FACI

The software development life cycle (Figure 4) showed Verification beginning during the requirements definition phase, long before software was available to be verified. This lead-time is necessary to build an organization with the expertise to verify the software independent of the design and development groups, and to develop a meaningful test plan.

The first step in this process involves development of test specifications which are high-level descriptions of the testing to be performed. These are almost entirely based on the software requirements and contractually must be reviewed and accepted by NASA. This activity, along with requirements design team participation, provides verifiers with an in-depth knowlege of the requirements.

The follow-on test procedures, completed during the software code and test period, describe the testing in detail. Since they include the test timeline, the data to be collected for analysis, and analysis techniques, these test procedures must consider both the software design and the requirements. It is procedures development that gives the verifier an understanding of the implemented code.

Prior to formal delivery of the software at FACI, Verification begins a test case development and validation period, building simulations from the procedures and executing them in the SDL as a "dress rehearsal" for the formal verification. This activity provides verifiers with experience in using the SDL test bed and also serves as a final validation of the SDL capabilities before FACI.

Test Documentation and Review

Both test specifications and procedures are centrally documented in an Integrated Test Plan (ITP). For STS-1 the Verification ITP is comprised of 10 books. The first eight books document the detail/functional testing. Each is associated with a major software area, e.g., operating system, vehicle checkout software, guidance, navigation, and control software, etc. The ninth book documents performance testing. These first nine books cover all Verification testing and are reviewed and approved by the NASA software monitoring organization, the NASA Spacecraft Software Division (SSD), under the authority of the Space Shuttle Orbiter Project Office. Once baselined, the specifications portion of these books cannot be changed without the formal approval of NASA/SSD.

The content of the tenth book grew out of experience gained during Verification of the Shuttle Approach and Landing Test software. At that time the NASA Space Shuttle Orbiter Project Office, along with representatives from the avionics engineering community, reviewed in detail the entire Verification test program at the Configuration Inspection (CI), and used this review as a basis for software acceptance. In contrast, the plan for STS-1 called for the NASA Project Office to delegate a large part of this review to NASA/SSD as an ongoing activity and to review only key testing areas in detail at the CI. Book 10 of the ITP defines this key subset of the approximately 1100 verification test cases. This subset, which includes all of the performance cases and a few detail/functional cases, will be used as criteria for software acceptance at the STS-1 CI. Selection of CI acceptance tests has been coordinated with NASA and the general Shuttle engineering community over the past 31 months. The content has been baselined and under NASA Orbiter Project Office configuration control since mid-1978.

Formal Verification - Configuration Control

In the formal verification period, FACI to CI, the Verification organization assumes configuration control responsibility for both the software and simulator. All software changes introduced after the FACI delivery, both discrepancies and requirements changes, require explicit closure by the Verification area.

Such explicit closure actions include re-execution of test cases (*regression testing*), execution of new cases, code inspections, formal requirements waivers, or explanatory notes to software users.

Configuration control of software discrepancies (DRs) starts *with all DRs, regardless of originating facility, being maintained* in a single data base (see Figure 8). Open discrepancies are reviewed weekly by a committee made up of representatives from all IBM software organizations and NASA/SSD. DRs are dispositioned in one of three ways: a decision is made to correct the discrepancy; the DR is not considered critical to the STS-1 mission and no software modification is recommended (a requirements waiver results); or the DR is determined not to be a software problem. The latter two dispositions are made only with the originator's agreement. *Appeals for contested dispositions* are resolved either by NASA's Test & Operations Board, to be *discussed later*, or the NASA Space Shuttle Orbiter Project Office, i.e., Orbiter Avionics Software Control Board (OASCB).

Following disposition and implementation (*if required*), DRs are forwarded to the Verification group for independent re-assessment and *formal written closure*. As mentioned, closure action may require explicit retest or code inspection regardless of whether a software modification was required. Following written closure of DRs by Verification each DR is coordinated again with NASA/SSD or the NASA Orbiter Project Office for formal concurrence.

Explicit closure of requirements changes incorporated after the FACI is similar to the closure process for DRs. Approval for implementation, however, is the responsibility of the NASA Orbiter Project Office.

6. FIELD TEST - EARLY CUSTOMER INVOLVEMENT

The ideal software development cycle discussed earlier (*Figure 4*) *is only realistic when applied to relatively small, well-*defined software systems. High requirements change activity associated with developing systems and schedule restrictions make it especially impractical when the software is one of many complex systems to be integrated.

Early in the Shuttle program it was recognized that the ultimate users of the software could not wait for the complete package to be developed, verified, and delivered. Since the software was such an integral part of the overall system, checkout of customer test simulators and crew trainers, and more important, the build-up of the actual Shuttle orbiter could not begin without it. To

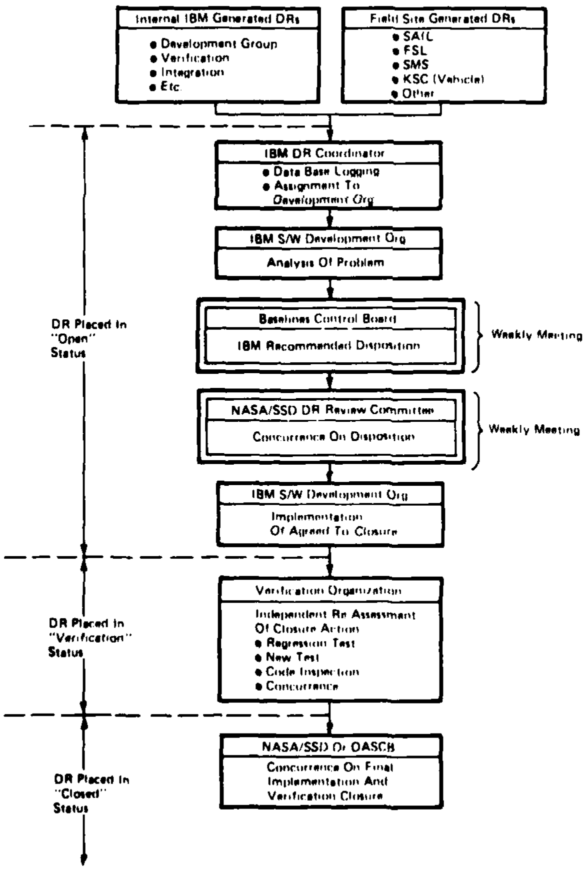


Figure 8. Software Discrepancy Closure Procedure

minimize the elapsed time between software requirements definition and the end of the Shuttle integrated testing, a series of interim releases of the software to the customer was defined

The releases were first separated by flight phase or memory configuration, i.e., ascent, entry, etc., staggered in time by several months, and a FACI associated with each. Further, several early "drops" of the software preceded each FACI release, allowing a buildup of capabilities. The advantages to the customer are obvious, but this approach also provides certain advantages to the software organization. It fosters a gradual development and test approach, exposing the software in small increments to both verification and field users. This allows early identification of software discrepancies and eases problem isolation so often difficult in large fully-integrated systems. This incremental approach also exposed the software and data processing system to the actual flight hardware interface at a much earlier state in the program.

The STS-1 software development program has had 17 interim releases in the 31 month period starting in October, 1977 (see Figure 9). Although full software capability was provided after the ninth release in December 1978, an additional eight releases of the software have been necessary to accommodate the high requirements change and discrepancy activity inherent in large, complex, first-of-a-kind software systems.

Along with the advantages of this early release philosophy also came the inevitable disadvantages of configuration control. Because the installation of new software releases into field sites is not instantaneous or without cost, there is always some resistance to move up to new systems as they become available. Experience has shown that it is not unlikely to have the various Shuttle field sites using different past releases of the software and, in one extreme, a single site using multiple releases for different types of testing. All of this points to the need for a strong Customer Support and Field Test organization with a more expanded role than that described by the ideal development cycle of Figure 4.

STS-1 Customer Support and Field Test - The Test and Operations Group

Test and Operations (T&O) is a support organization which consists of four Shuttle test site resident groups and a staff group in Houston. The Shuttle test sites supported are: Flight Systems Laboratory, the Shuttle Avionics Integration Laboratory, Shuttle Mission Simulator, and Kennedy Space Center. The T&O organization is charged with six basic responsibilities: user training, assistance in the preparation and review of site test procedures, flight software installation and maintenance, test support, mission support, and user liaison. Each of these responsibilities will be addressed in detail and their value to software development and verification will be identified.

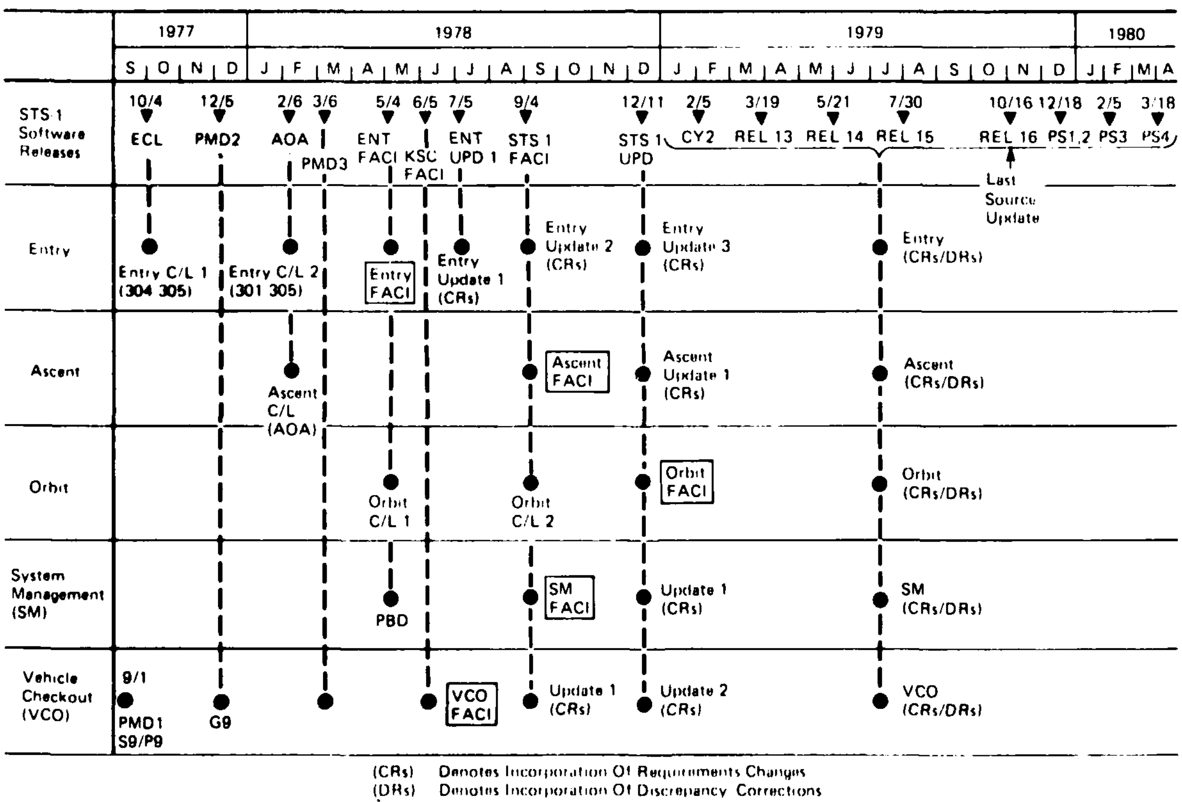


Figure 9. Interim Flight Software Releases

Site user training is provided in two steps. First, classes at the user facility cover the basic design and implementation of the flight software. The second step is release orientation. For each software release, training sessions familiarize the user with any new capabilities included in the release. Other topics include identification of changes from previous releases, and known anomalies and restrictions.

On request, T&O personnel assist users with test procedure preparation and review for both the vehicle and software. This practice ensures that the flight software is used properly, the required capabilities are available in the release being used, and alternate approaches are recommended when the desired capabilities are not available. These reviews also assist the Houston development organizations in setting software development priorities for each field release.

T&O installs and maintains flight software releases to the degree desired by the site management. This activity includes assistance in preparation of required procedures and installation of releases or release updates. Throughout this activity feedback is provided to the software development organization. Problems are identified and corrections needed to support vehicle or site testing milestones are defined. Requests for software fixes are made through the T&O Board - a NASA function which controls flight software maintenance to user facilities.

As part of the pre-release quality assurance process, T&O performs a load and execution test on all flight software releases. These pre-release tests are performed in at least one field site, in conjunction with the System Integration organization mentioned earlier. Site test support requires T&O to assist the sites in conducting tests and training personnel for a test or actual mission. This support includes planning, running, and analyzing tests. T&O personnel accomplish these functions by monitoring the site tests, and analyzing all apparent flight software anomalies. Problems identified in the software are directed back to Houston for resolution and correction. This activity provides the Software organization with additional insight into the behavior of the software in a vehicle environment and under mission conditions.

Mission support is provided to both the Mission Control Center in Houston and the Launch Control Center at Kennedy Space Center in Florida. T&O personnel support vehicle checkout for launch, launch countdown, and throughout the mission. All flight software anomalies detected during a mission are documented, data is gathered, and analysis is performed with T&O assistance. Additional resources needed to resolve the problem either from the Software organization or the SDL are coordinated by T&O. Following major tests or missions, a T&O "quick-look" report summarizes the problems encountered and provides problem status. After all problems have been resolved, a final report is written to identify the closure rationale. Again, flight software problems are reported to Houston for correction or final disposition.

T&O personnel act as a liaison between users of flight software at the sites and the software organization (see Figure 10). They also provide schedule coordination, assessment of priorities, problem reports, and patch coordination through the NASA T&O Board. The T&O Board provides final resolutions with assistance from the Orbiter Avionics Software Control Board (OASCB) of the NASA Space Shuttle Orbiter Project Office.

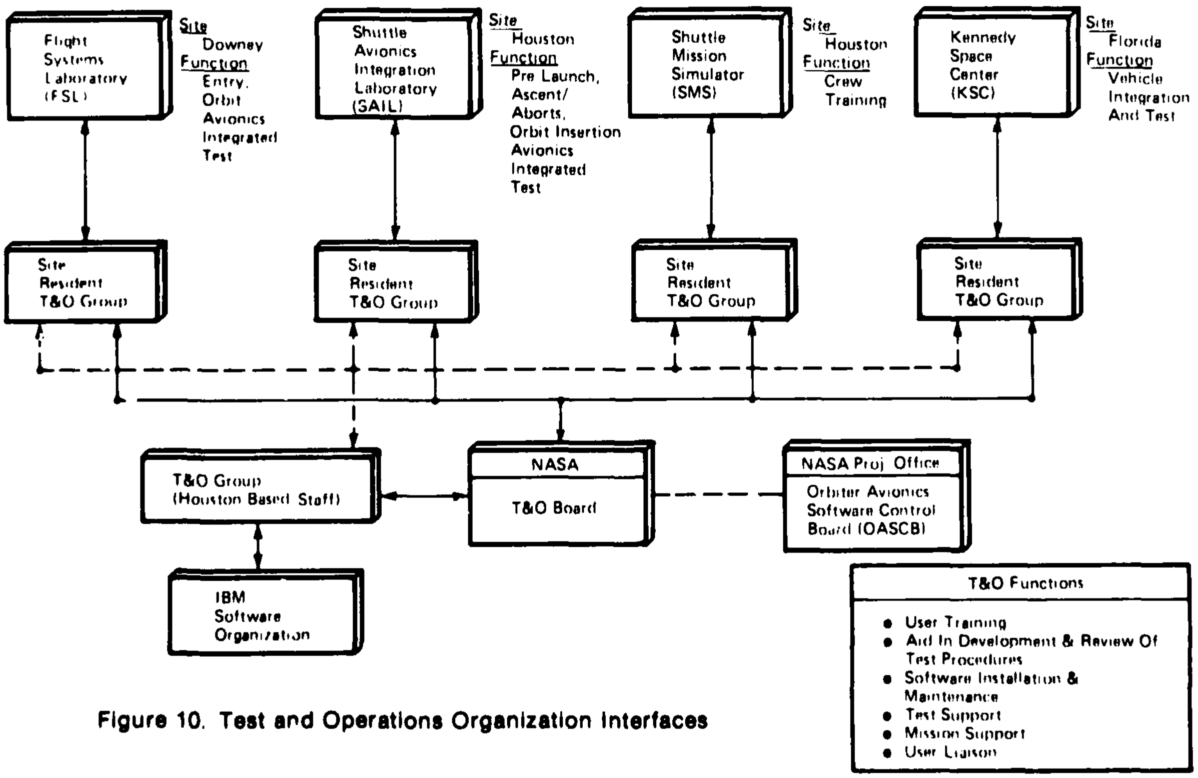


Figure 10. Test and Operations Organization Interfaces

The T&O functions covered thus far are general responsibilities that do not change during the life cycle of a software delivery. However, emphases does shift from one function to another as the program progresses. The software life cycle can be divided into three periods: pre-last-source-build, post-last-source-build, and post-Configuration Inspection.

During the first period, site-resident T&O personnel work closely with software users to identify software capabilities required for future tests. This information is provided to the Software Development organization to be factored into the scheduling of software capabilities. Software discrepancies are also reviewed for test impact and those affecting tests are identified for correction.

The emphasis during the second period is primarily on maintenance. Software anomalies that impact testing are identified and patches requested through the T&O Board. Periodic patch releases consistent with site test plans are scheduled for delivery. During this period, the T&O Board controls the maintenance activity.

The post-CI period is controlled by the Orbiter Avionics Software Control Board. All changes requested during this period must be approved by the OASCB. Requests for changes are coordinated through the T&O Board, and taken to the OASCB for final disposition. Again, the major emphasis is on finding and identifying problems rather than identifying needed capabilities.

7. STS-1 EXPERIENCE TO DATE

Software Change Activity

The software requirements change activity is shown in Figure 11. The number of change requests is measured from the programmatic baseline of the various requirements documents. As described in the figure, specific requirements books were baselined at different times.

Formal Verification of the STS-1 software began in early December 1978, shortly after the last requirements document was baselined. At this time all baseline capabilities necessary to perform the STS-1 mission were incorporated in a single software release (refer to Figure 9). Eight early releases of the software, distributed over a 14-month period, preceded this first "complete" delivery.

Since this delivery, high software change activity has necessitated nine additional releases of the software. The changes, both requirements updates and software discrepancies, are expected in such a complex first-of-a-kind system. Nearly 700 requirements change requests (CRs) have been received since

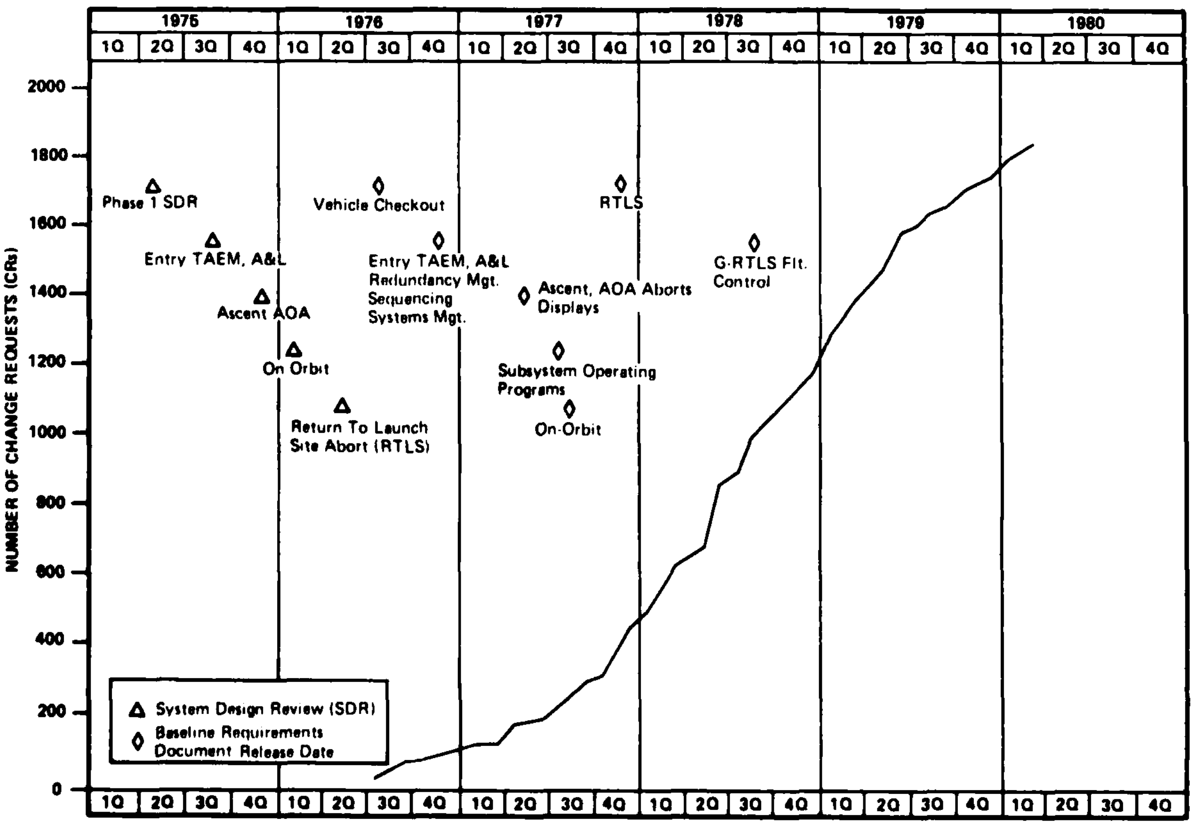


Figure 11. STS-1 Flight Software Requirements Change Requests (CRs)

TYPES OF DRs WRITTEN

Discrepancy Disposition	% Of Total
S/W Change Required	52%
Requirements Waivers Requested	4%
Change To [1] Requirements Baseline Necessary	8%
Determined [2] Not To Be A S/W Problem	36%

ORIGIN OF DRs

Originating Facility	% Of Total
Development And Integration (IBM)	46%
Independent Verification (IBM)	37%
Customer Field Sites	17%

(1) May Not Result In Software Change

(2) User Error, Simulation Problem, Hardware Problem, Requirements misinterpretation, duplicate DR (~ 9%)

Figure 12. STS-1 Software Discrepancy Statistics

December 1978 (refer to Figure 11). About 450 of these have resulted in software alterations; the remainder are documentation clarifications. The changes have ranged from the very simple, such as changes to initialization constants (I-LOADs), to the very complex, e.g., a redesign of the redundancy management software for the reaction control system.

In the same period, approximately 3000 discrepancy reports (DRs) have been written against the software. Of these, 52% have resulted in changes to the software (see Figure 12). An additional 4% were found to be software problems but have resulted in requirements waivers. The remainder have been determined not to be problems in the software. As previously mentioned, the Verification organization is responsible for explicit re-assessment and closure of all discrepancies and requirements changes whether or not a software alteration resulted.

Current Verification Status

At this time, the Verification activity is essentially in the regression or retest portion of its test plan. As of June 1979, the detail-/functional test organization had completed its base-plan, i.e., all cases had been executed and analyzed at least one time. The major activities since June have been to retest those areas which have been changed due to CRs and DRs, and to complete certain audits and surveys associated with the common-function tests.

The performance area completed its base-plan as of November 1979, and is also in a regression test period. The choice of tests to be rerun in the performance area is driven not only by CRs and DRs, but also by mission timeline updates, trajectory changes, and crew procedures modifications.

The cost of a total independent Verification program compared with that of other software activities is difficult to estimate because of the many overlapping functions. A gross estimate, however, would place it at about one-half the software development cost, depending on the level of testing performed within the development groups. The effectiveness of the independent verification of the Shuttle software can be measured by the number of problems uncovered, or, from another perspective, by the number of problems which would have gone undiscovered if the "Verification Test Plan" had been executed by the same personnel responsible for the software development. While these are difficult numbers to interpret, approximately 37% of the total discrepancies found in the software were found by the Verification group. Many of these were uncovered in off-nominal situations and generally represent real system problems. Error-free software is a difficult goal to achieve, and as noted earlier, can only be approached asymptotically. The fresh look at the software by an independent group equally familiar with both the requirements and the design must bring the project closer to this goal. Another indirect measure of the value of the Verification activity can be found by analyzing the field-site-generated DRs/corrections shown in Figure 13. From these graphs it is evident that the overall quality of the software is improving.

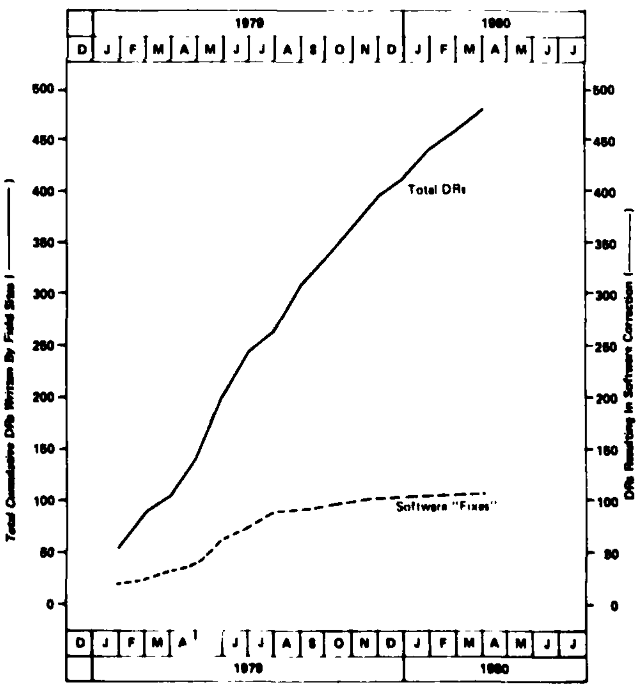


Figure 13. STS-1 Software Discrepancy Status for Field Sites

8. SUMMARY - ASSURING SOFTWARE RELIABILITY

The following outline summarizes the key factors in producing a Shuttle software system which meets program requirements. All major software activities are listed, along with items considered integral to their success.

Software Development and Integration

- Early involvement in the development of the software requirements through a dedicated analysis organization.
- Adequate documentation of the requirements under strict configuration control.
- Early definition of programming standards and techniques, and enforcement of these through use of a high order language/compiler as well as formalized review of the software.
- Centralized configuration control of the test and build of the evolving system.
- A thorough but limited system test plan to assure that the integrated system is usable under nominal conditions before delivery for formal Verification or for the customer's early use.

Software Verification

- Use of an independent line organization without managerial or personnel ties to the development organizations.
- Use of personnel with engineering analysis skills and systems experience.
- Maintenance of an adversary relationship with the developers of the software, i.e., the assumption that the software is essentially untested when received.
- Sufficient lead-time to develop a thorough test plan. This includes sufficient time for involvement in the software requirements definition and the software design.
- A test plan which provides an independent test against requirements, a functional level of testing and appropriate emphasis on code surveys and audits to address problems not easily uncovered by testing.
- A performance or system-level test plan which emphasizes software user (customer) involvement at all stages.
- Configuration control of test documentation, test execution and analysis.
- Configuration control of changes to the software test article along with a formal plan for re-test.

Early Customer Use of the Software

- Delivery of early (but usable) versions of the software to the customer to increase "shelf life" and provide exposure to operational flight hardware.
- Use of a capable customer-site-resident liaison and maintenance group able to troubleshoot problems and provide temporary solutions.

Simulator - Test Bed

- Early requirements definition involving all future users.
- A thorough test plan which includes a final validation by users of the facility before formal software testing begins.
- An adequately-staffed maintenance and test group to address updates and discrepancies.
- Configuration control of discrepancy corrections and updates to simulator versions being used for software testing.

9. FUTURE ACTIVITIES

While the development and verification of the Shuttle primary software for STS-1 poses unique challenges, the future involves many unsolved problems associated with producing "man-rated" software for the high flight frequencies projected during the Shuttle's operational phase. These flights will require rapid reconfiguration to accommodate a variety of payloads and trajectories. This will cause changes, not only to the crew and payload support software, but also to the guidance, navigation, and control systems. NASA has recognized this problem and is moving forward with two separate activities. The first is to define a Software Production Facility (SPF), which will serve as a follow-on to the SDL facility, and can support the anticipated reconfiguration activity. This includes design of data base structures, evaluation of resource requirements, generation of operating procedures, and definition and development of preprocessors to allow rapid reconfiguration of program data.

The purpose of the second task is to reduce the test time required to certify the software for flight. The first objective in this activity is to define and develop tools to aid in the analysis of simulation test data. The second is to develop and execute a test plan to stress the software over the extremes expected during the operational phase. This plan will include variations in mass properties, orbital inclinations, altitudes, etc., and will provide a base set of test cases to be executed on the actual flight software load.

The definition of the SPF and the definition of additional analysis tools are currently underway. Plans are in place to begin the stress case definition and execution in the third quarter of 1980.

COMPUTERS FOR WEAPON SYSTEMS -- A LOOK AHEAD

David A. Herrelko, Captain, USAF

Since our national defense posture depends more on superior technology than on strength of numbers, we must treat our technology advantage as a precious resource, to be preserved and extended. In an era of spectacular advances it is hard to measure our technology "edge". In a time when the purchasing power of the Defense dollar is shrinking, it will be even harder to keep our lead. National security rests on split-second timing and sure, measured control of military power. A key factor in the power equations, and a critical part of our technology lead, is computational capability - especially in computers embedded in weapon systems.

Computers are integral to virtually every modern military system. Almost everything that flies carries embedded computers, from satellite to bomber to our smallest remotely-piloted vehicle. Military surface systems, as well, rely on computers. These rugged digital systems range from single-chip processors to giant computer centers with mainframe and the full array of peripherals. We use military computers in laser rangefinders, radar signal processors and electronic warfare suites. Our embedded computers perform navigation, weapon delivery, maintenance, battle management, and a host of other tasks. These new capabilities are expensive and hard to develop. To keep our technology lead in fielded systems, we must manage computer technology so these systems become, not cost multipliers, but force multipliers.

We've all heard that an explosion of electronic technology is underway, and it's true. Although explosions are hard to manage, we should welcome this technology explosion, so long as we can harness part of its power to satisfy real mission needs. The Air Force Systems Command is nearing the completion of a study identifying computer technologies to meet weapon systems needs for the next twenty years. The Computer Technology Forecast and Weapon Systems Impact Study (COMTEC-2000) defines policies and R & D programs that will capitalize on commercial advances in computer technology and also satisfy technology needs unique to the Air Force. The COMTEC-2000 study indicates:

- o Hardware is advancing at the speed of light.
- o Software is proceeding at the speed of sound.
- o Systems understanding evolves at the speed of human thought.

Hardware Forecast:

"Buck Rogers" projections of hardware technology advances all begin to look the same after a while - every forecast is jammed with exponential curves, which I'll spare you in this short note. A few highlights from COMTEC-2000 are worth special attention:

In microcircuitry, expect a thousandfold improvement in cost, speed, and size over the next decade. A single chip microprocessor capable of a million instructions per second - "a MIP on a chip" - could appear in as soon as 18 months. By 1985 we should see, on one integrated circuit, the processing capability of an IBM 370/158. Bubble memories and charge-coupled devices will displace electromechanical bulk memories, especially in space, where we need systems that will survive, unattended, for five years. Still more fantastic potential exists in gallium arsenide and Josephson junction devices, which will take us beyond the limits of conventional silicon technology. Microprocessors will proliferate - we will find them everywhere, doing tasks never before imagined. The challenge to the software community and to system architects is to capitalize on this wealth of hardware technology.

Software Forecast:

The software picture for the next twenty years is harder to project. Unlike hardware, the software world lacks a standard set of metrics by which to judge performance. Even the vocabulary in the field has not matured to a standard set of words and meanings.

No quantum leaps are forecast, but problem-oriented higher-order languages will grow in power and efficiency, replacing assembly code in most applications. When the

Air Force selects a higher-order language, logistics considerations will dominate technical ones, as increasing emphasis is placed on the total life cycle cost of the software support system. Unlike our experience with COBOL in the 1960's, however, we can't expect government preference for one higher order language to guarantee industry acceptance.

There will be a software personnel shortfall of about thirty percent nationwide, within 10 years. Training efforts will intensify, but this critical shortage will limit DOD industry. Modern programming methods will double productivity, and interactive systems will further aid programmer effectiveness. "Automatic programming" from English specifications to machine code is far downstream, but progress will continue in automating the software job.

Systems Forecast:

The COMTEC-2000 crystal ball is most obscured in the area of systems forecasting, and this is disturbing. Hardware breakthroughs and the more gradual improvements in software engineering cannot be fully exploited until we develop and practice a modern approach for systems design and development. If the maturity of a technology is marked by the existence of a common vocabulary and standards of performance, the systems aspect of computer technology must be our weakest area.

There will be system-level changes, driven by the hardware explosion and software techniques. For combat systems where secure communications cannot be guaranteed, command, control, and communications (C^3) and aircraft systems will need methods for multi-level security, fault tolerance, and graceful degradation. Giant uniprocessor mainframes will yield, in many applications, to distributed systems, with "smart" terminals widely used in stand-alone or network modes. Conventional hierarchies of networked machines will be challenged by peer-coupled systems, but much effort remains before we understand distributed data bases and network security.

COMTEC-2000 Initiatives:

The COMTEC-2000 study considered these forecasts and measured their impact on Air Force weapon systems. From this work, literally hundreds of ideas emerged. The final phase of the study focused on twelve key issue areas, recommending program and policy initiatives to exploit opportunities and to overcome potential shortfalls. The twelve issue areas are:

1. Solicon Technology
2. Software Personnel Shortfalls
3. Software Technology
4. Software Life-Cycle Investment Strategy
5. Distributed Processing Technology Needs
6. Technology Exploitation Time Lag
7. Solution Methodologies Shortfalls
8. Computer Resource Standardization
9. Acquisition/Management Approach for C^3 Systems
10. Nonsilicon Technology
11. *Man-Machine Interface Technology*
12. Data Generation and Handling.

The COMTEC-2000 report is available through the Defense Technical Information Center, Cameron Station, Alexandria, VA 22314:

Vol. I Summary
AD B 034954

Vol. II Technical Data
AD B 034955

Vol. III Issue Panel Reports
AD B 041871.

SOFTWARE STANDARDIZATION AND MIL-STD-1750

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NAECON '80, May 20-22, 1980

Note: The opinions expressed in this paper are those of the authors, and are not necessarily those of the United States Air Force, the Air Force Systems Command, the MIL-STD-1750 Users Group, or Northrop Corp.

ABSTRACT

An introduction to the need for software standardization is given, and the role of MIL-STD-1750 (USAF) is described in the context of the proliferation of languages and computer architectures used in weapon systems. The status of the Air Force's Airborne Computer Instruction Set Architecture (ISA) is reported, and a technical overview is made of the ISA and of enhancements to it proposed by the industry-based MIL-STD-1750 Users Group to the government control board. Potential applications are described, advantages and disadvantages of the approach are given, and challenges that remain are identified.

INTRODUCTION

Since our national defense posture depends more on superior technology than on strength of numbers, we must treat our technology advantages as a precious resource, to be preserved and extended. In an era of spectacular advances it is hard to measure our technology "edge." In a time when the purchasing power of the Defense dollar is shrinking, it will be even harder to keep our lead. National security rests on split-second timing and sure, measured control of military power. A key factor in the power equations, and a critical part of our technology lead, is computational capability - especially in computers embedded in weapon systems (1).

Computers are integral to virtually every modern military system. Almost everything that flies carries embedded computers, from satellite to bomber to our smallest remotely-piloted vehicle. Military surface systems, as well, rely on computers. These rugged digital systems range from fuel-savings advisory systems, crash data recorders and display controllers to navigation/weapon delivery systems, electronic warfare (EW) suites, and large battle management systems. These new capabilities are expensive and hard to develop. To keep our technology lead in fielded systems, we must manage computer technology so these systems become, not cost multipliers, but force multipliers.

The Air Force Systems Command has recently completed a study identifying computer technologies to meet weapon system needs for the next twenty years. The Computer Technology Forecast and Weapon Systems Impact Study (COMTEC-2000) indicates:

- o Hardware is advancing at the speed of light
- o Software is proceeding at the speed of sound
- o Systems understanding evolves at the speed of human thought (2).

The explosion in electronics technology - like any explosion - is hard to manage, but the phenomenon is welcome, so long as we can harness a portion of its power to satisfy real defense needs. All the curves of technological progress show positive, dynamic growth - the only curve that goes the wrong way is the cost of software.

SOFTWARE COSTS

The Air Force's software costs are skyrocketing. The demand for software for weapon systems is typified by Figure 1, which shows the growth trend for on-board avionics memory (3). Any errors in the chart are on the conservative side: many computers are deeply embedded within subsystems and many systems are being updated with more memory. Similar curves exist for command, control and communications (C^3), radar processing, EW, armaments, and space applications.

Software costs are growing in a relative sense, as well. Figure 2 (derived from Barry Boehm's famous diagram) suggests that hardware breakthroughs and expanding applications of computers are shifting computer systems costs toward software development and support (4). These curves

are most striking in their impact on a labor-intensive industry, particularly in the context of a severe software personnel shortage, the limited prospects for improving programmer productivity, and the often overlooked "hidden costs" of software (Figure 3). The dramatic growth in operational software depicted in Figure 1 is just the tip of the software iceberg (3). For each system with embedded computer resources, the program director must manage - and pay for - an entire complex of development and support tools.

The Air Force Systems Command is conducting a three-front campaign to improve the acquisition and support of embedded computer systems through competition, technology, and standardization. These efforts, when guided by sound management principles, can hold the line on costs, and produce better fighting systems.

Competition is a key to our free enterprise system. No single initiative can do more to improve the cost-effectiveness of our military systems. Electronic technology efforts span too broad a spectrum to cover here, but a few are particularly relevant. The Air Force is concentrating on those areas not likely to be advanced by the commercial market alone: radiation hardening, packaging for severe environments, fault-tolerant computer design, and very high speed integrated circuits are relevant examples.

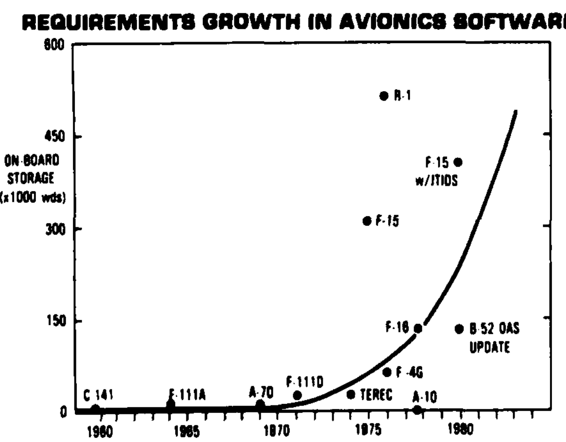

Figure 1. Memory Requirements Growth in Initial Versions of Avionics System

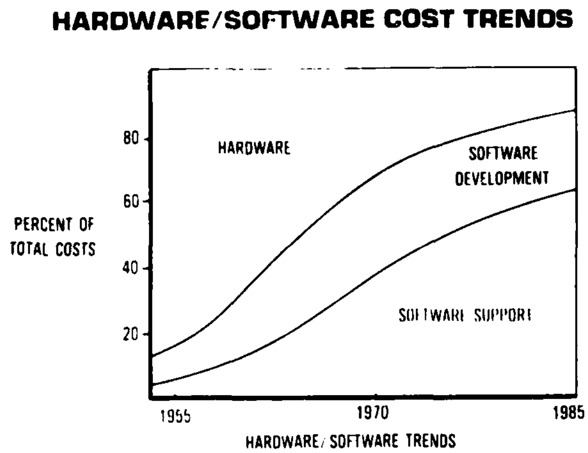

Figure 2. Computer Systems Life-Cycle Cost Trends

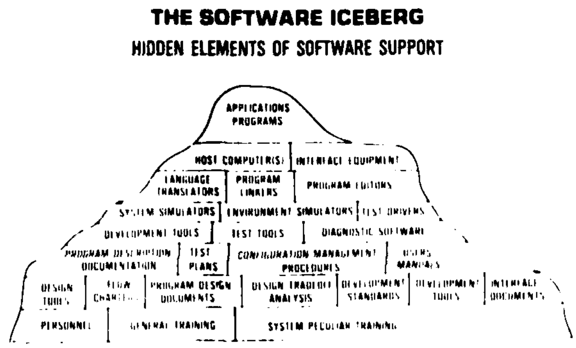

Figure 3. The Software Iceberg -- Hidden Factors in Software Support

STANDARDIZATION

Standardization can greatly reduce the needless proliferation of computers, architectures and languages in the military inventory (5), but great care must be taken so that standardization efforts do not prevent competition or discourage innovation. In order to exploit the best hardware breakthroughs and to permit all sources to compete for military business, emphasis should be placed on standards for computer languages, architectures, and interfaces. Observations (e.g., 6, 7) of the literally hundreds of computers and languages used in military systems, and the resultant "M x N" problem (Figure 4) of proliferating combinations of languages and target architectures have led to DOD Directive 5000.29, which fosters the use of higher-

order languages (HOL), and DOD Instruction 5000.21, which seeks to bound the set of HOLS used in embedded computer systems (8, 9). The Instruction Set Architecture (ISA) Standardization Panel of the Office of the Secretary of Defense Management Steering Committee for Embedded Computer Resources has drafted and recommended the publication of DOD Instruction 5000.5X. The thrust of this new instruction (10) is to identify and foster the use of an approved set of vendor-independent ISAs which may be implemented with the latest hardware technology. This approach avoids the technology freeze often encountered with "black box" standardization approaches, and still permits additional levels of standardization (interfaces, F-cubed, or piece-part) where they are appropriate and necessary. An example of such a government-owned ISA is MIL-STD-1750 (USAF), "Airborne Computer Instruction Set Architecture" (11).

MIL-STD-1750

MIL-STD-1750 recently celebrated its first birthday as the Air Force standard ISA. Born at Wright-Patterson Air Force Base as part of the Digital Avionics Information System (DAIS) program, 1750 evolved through successive design iterations, under the guidance of Dr. Donald Moon, Dr. Mark Michael of the Air Force Avionics Laboratory (AFAL), and Mr. Joseph Gebele of the Aeronautical Systems Division (ASD). Early work produced the AN/AYK-15 DAIS processor. This computer's ISA was evaluated and enhanced (12, 13) and MIL-STD-1750 (USAF) emerged. 1750 has since been used to build the AN/AYK-15A computers (14).

MIL-STD-1750 (USAF) defines a general purpose digital computer architecture, as seen by a compiler or by an assembly language or machine language programmer. 1750 prescribes data and instruction formats, computer organization and operation at the level necessary to exploit a common base of software support resources - hardware, software, and people. The standard is not a single computer design, a form-fit function specification, or the drawings for one vendor's "black box".

MIL-STD-1750 is intended to control the proliferation of computer designs in our weapon systems. Use of the ISA standard can reduce risk for program managers. Government and contractors alike will be able to exploit a growing base of people, computer programs, and support facilities - developed, validated and paid for before any program commitments are made. The program manager can initiate software development well before the actual mission computers are delivered. Most importantly, 1750 will focus competition on a proven ISA, owned by the Air Force and available to all bidders.

MIL-STD-1750 is strongest when used as part of the Air Force Systems Command's triad of embedded computer system standards:

- MIL-STD-1553B, our multiplex bus standard (15) is used in Air Force, Army, and Navy systems, and enjoys wide use internationally
- MIL-STD-1589A (USAF), "JOVIAL (J73)", is the Air Force's HOL-of-choice for embedded computer systems (16, 17, 18, 19)
- MIL-STD-1750 (USAF), although the "new kid on the block" in terms of date of publication, has evolved over five years, in open forum with industry.

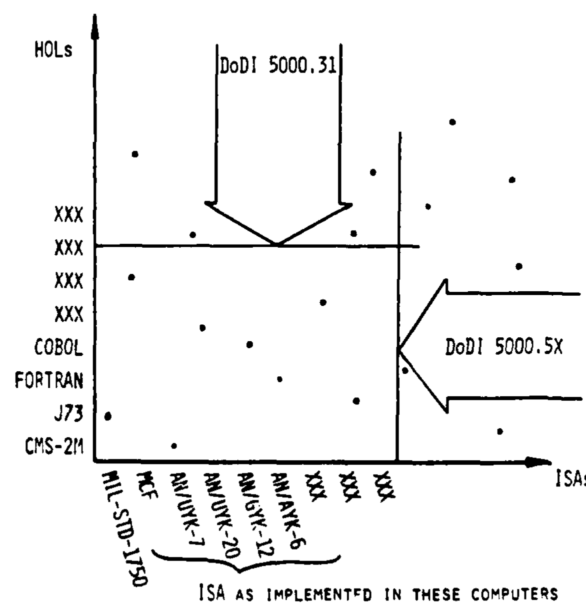

Figure 4. DOD Instructions Bound the M x N Problem

MIL-STD-1750 STATUS

How is MIL-STD-1750 doing? It works - and works well! The study by Dietz and Szewerenko (20) reports that MIL-STD-1750 outperformed the ISAs of the AN/AYK-14, Digital Equipment Corporation PDP-11/70, and Data General Eclipse C/330 in terms of memory activity and program size, and that 1750 was comparable to these ISAs in terms of processor activity. Bradley (21) studied 1750's potential for electronic warfare, and found that the 1750 ISA can support EW signal processing and that 1750's ISA would outperform the ISAs now used in those systems. Denton, et al (22) found 1750 ISA basically sound, but stated that while MIL-STD-1750 compares favorably with other airborne computer architectures, several "rough edges" remain. Denton and Samuelson (23) proposed modifications and extensions to 1750, which they believe would improve overall cost and performance by twenty to forty percent.

Four implementations of 1750 have already been built, in the Air Force Institute of Technology, for AFAL, and for ASD. A total of thirteen computer manufacturers and avionics systems houses are developing 1750-based computers. Many of these firms see the opportunity to reduce production costs of their existing families of computers through microprogram emulation of MIL-STD-1750. Extending the production runs of already deployed computers will exploit economics of scale, and vendors will ride the production learning curve to lower unit costs. This, in turn, will reduce hardware life cycle cost in a global sense, for the Air Force, and for any organization buying from these military computer families. Cutting the acquisition costs of computers that may not use the 1750 ISA was not the original goal of the DAIS program, but it is a most desirable spin-off. The most common technology for early implementations of 1750 is a multiple-card bi-polar bit-slice emulation, but other approaches are attracting attention. Vendors may exploit a variety of technologies in building a 1750-based computer. For weapon systems applications, low-power I^2L using gate arrays, radiation-hard CMOS/SOS, and compact very high speed integrated circuit (VHSIC) approaches are attracting attention.

SUPPORT CONSIDERATIONS

Natural concerns for an emerging ISA standard include issues of certification and software support. ASD's Systems Engineering Avionics Facility (SEAFAC), which support military standards requirements and in-house hot bench activities (24), is the MIL-STD-1750 Control Facility. SEAFAC is sponsoring two studies of how a rigorous certification capability can best be provided. While a provisional acceptance test program may be said to exist, SEAFAC plans a more robust certification capability. The results of the certification studies will be presented at the next quarterly meeting of the MIL-STD-1750 Users Group, and industry comments will be solicited.

Developing a mature set of software support tools is essential to successful ISA standardization, and work to this end is well under way. Early parallel efforts have produced a variety of assemblers, simulators, and linkers/loaders that run on a variety of hosts. A formal course is one set of tools that has already been completed. AFAL, ASD, and the several contractors involved are focusing on a Common File Format that should ease the hoped-for eventual convergence to a common set of tools, government-owned, and available to all through the Federal Software Exchange. Two separate J73 compiler developments targeted to 1750 are under way. The MIL-STD-1750 Users Group Software Tools Committee is continually updating an annotated catalog of the tools available (25).

MIL-STD-1750 USERS GROUP

The MIL-STD-1750 Users Group is a highly successful synergy of talent from industry and government. The cream of industry's embedded computer architects has joined with compiler experts and systems houses, and they are complemented by government representatives from the research, acquisition, logistics, and operational commands of the Air Force. The users group was formed in August 1979, and has been a valued contributor in the refinement of MIL-STD-1750A. The group's energetic - and expert - technical review of the standard has greatly improved the proposed MIL-STD-1750A, which we expect will be

our standard for years to come. Membership in the group is open to all comers; the only dues asked are an open mind and a willingness to participate on one of the committees shown in Figure 5. Having greatly aided in refining MIL-STD-1750A, the Users Group is shifting its emphasis to matters of support tools and certification methods. A typical meeting is attended by 80 or more people, representing dozens of companies. Inquiries may be addressed to the junior author, who is Secretary of the group.

MIL-STD-1750 USERS GROUP

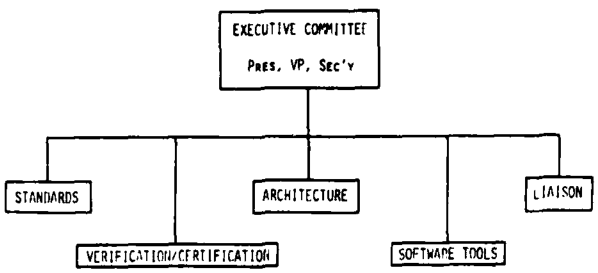

Figure 5. The MIL-STD-1750 Users Group Organization

MIL-STD-1750 CONTROL STRUCTURE

Figure 6 depicts the government control structure. The Deputy for Avionics Control (a Joint AFSC/AFLC organization) is the MIL-STD-1750 Control Agent, and serves ex officio as Chairman of the Control Board. The Control Board is composed of government representatives from laboratories, System Program Offices, Air Logistics Centers, and the using commands, as well as ASD enigneers. Participation is open to other military organizations having a stake in the standard; participation by other Services is encouraged. The Board is charged with reviewing all proposed changes to the standard, and making recommendations on technical and management matters to Headquarters, Air Force Systems Command (HQ AFSC). The immediate task of the Control Board is to evaluate the change pages that are proposed for the enhanced MIL-STD-1750A (USAF), and to recommend a course of action to HQ AFSC. By the publication date of this paper, we hope that MIL-STD-1750A (USAF) will have been released for publication.

MIL-STD-1750 CONTROL STRUCTURE

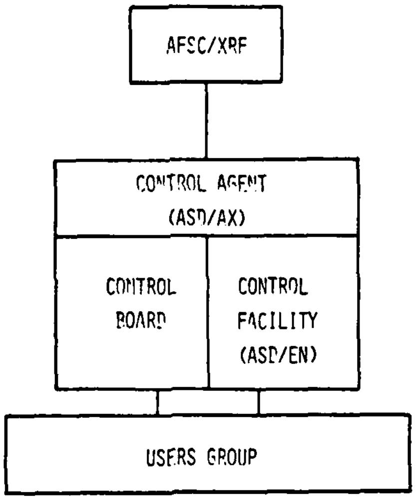

Figure 6. The MIL-STD-1750 Control Structure

TECHNICAL OVERVIEW

MIL-STD-1750 (USAF), 21 February 1979, is basically a "16-bit" ISA, with 16 user-accessible general registers. A rich complement of 16- and 32-bit instructions are provided, with referencing modes including: instruction counter relative, memory direct, and memory indirect. The importance of the stack as a data structure is recognized by PUSH and POP instructions which access an implicit stack pointer. Any of the general registers may be used as a return stack pointer, in recognition of the need for a separate stack for return linkage.

Six data types are recognized: bits, bytes, 16- and 32-bit fixed point, 32- and 48-bit floating point. Data referencing modes include: register direct, memory direct (indexible), memory indirect (pre-indexible), immediate long, immediate short, base relative (0 to 255), and base relative indexible. Of course, not all referencing modes apply to all operations. The short-format base-relative addressing facilitates subroutine argument and random array element access. The base-relative indexed addressing eases indexing through an array in a subroutine

when the array address is passed as an argument. The short- and long-format immediate addressing modes make the use of constants easy.

An excellent complement of shift instructions is given, including variable-length shifts with the count contained in a register. A special branch instruction exists for closing loops, and a separate interrupt vector (new IC, new SD, new IM) is used for each interrupt source.

It is this architectural depth and breadth which make MIL-STD-1750 the basically sound design that it is. Several aspects of the ISA as first issued have been identified in Users Group committee work, however, that made refinement of the ISA an important task. Many more technical issues were raised in the Standards and Architecture Committees than could be resolved in the time permitted. The Air Force recognized that a good, workable military standard "on the street" was far more useful than an almost-perfect one that was constantly being refined. Due to pressing program needs, the Air Force representatives asked the Users Group to respond to a 15 February 1980 deadline for recommendations on the new standard. Accordingly, the Users Group tackled the usual ambiguities and typographical errors, and also recommended enhancements in selected areas of the architecture. Due to the time constraint several interesting problem areas could not be pursued in depth and many technically valuable proposals could not be incorporated in the Users Group recommendations. The diverse backgrounds of the participants in the Users Group discussions caused the ISA and proposed changes to be scrutinized from various points of view. Issues raised included:

- efficiencies of hardware/software implementation and operation
- relative ease of software implementation and checkout
- relative ease of use of instructions
- life cycle costs

Change proposals exemplary of those the Users Group has made to the Control Board include:

- definition of processor Reset state and Power Up state
- addition of paging scheme for memory expansion (from 64k words to one million words)
- addition of privileged instruction feature
- addition of extended-capability I O instructions
- definition of operation of Timers A and B
- clarification of operation of "Clear Fault Register" I/O instruction
- reassignment of base-registers and reversal of original stack pointer arithmetic

The standard is by no means the ultimate in computer architectures - it was not intended to be. While many changes that might have made 1750A technically better did not get Users Group endorsement, those that did emerge will do much to enhance the already broad appeal of 1750/1750A.

POTENTIAL FUTURE APPLICATIONS

The 1750/1750A ISA can contribute to reduced risk and cost in a wide variety of military applications, whether airborne, ground- or space-based. Potential applications include:

- fuel savings advisory systems
- optical sensor processing/control
- navigation
- stores management and weapon delivery
- fuel flow and center-of-gravity control
- controls/display management
- electronic warfare
- encryption/decryption
- radio frequency controllers

- auto-land systems
- radar processors
- engine malfunction detection and diagnosis
- automatic test equipment
- intelligence processing
- battle management systems
- command, control, and communications
- terminal guidance and fuzing control
- data compression
- digital voice synthesis/recognition

ADVANTAGES AND DISADVANTAGES

There are good reasons to use 1750/1750A. It is vendor independent, and is not tied to any hardware specifications. Program managers will be able to rely on a set of proven support tools - schedules will be shorter, costs lower, and we'll have fewer development "surprises." The Air Force can save millions across the life cycles of many systems. 1750/1750A will let us exploit the hardware technology explosion without "locking in" on a single box. Competition will be wide open - to all bidders.

Concerns about 1750 are real, however. It could be better, but time constraints did not permit it. The ISA is a fairly new design, but it has been tested, proven and is well-understood by the industry. Our support software is several months away, but once it is "in place," all will benefit from it. The Air Force must fund and man a control structure and validation facility, but the costs of continued proliferation of ISAs is far greater than this. As with any standard, 1750/1750A is another constraint on the design process - but we think it a helpful one, if common sense is used. 1750/1750A is not suited for all computing tasks, nor was it intended to be; it should be used only in those portions of the spectrum of embedded computer applications where it can perform well. Still, 1750/1750A can perform many jobs better to best.

THE FUTURE FOR MIL-STD-1750

The emerging Air Force pattern indicates that, unless there are compelling technical and life cycle cost reasons to the contrary, 1750/1750A shall be used to the maximum extent possible in airborne embedded computer systems. All indications are that ground, space, and armament systems will receive similar guidance soon. The greatest difficulty to overcome in fielding any new standard is that no program manager or vendor wants to be first. The multiplex bus standard (1553B) encountered the same early "friction loss", and has become an international success. MIL-STD-1750 has overcome its first hurdles, and has high potential for success.

The essential factors remaining to ensure that success are:

- a broad enough scope of applicability
- good interrelationships with related standardization efforts
- expectations of stability, balanced against
- assurances that major concerns will be heard
- a broad base of support in the community that <u>uses</u> computers
- a demonstrated reduction of the total life cycle cost associated with embedded computing.

This is no simple shopping list, in fact, it would appear to pose a significant challenge to us all. The continued communication and cooperation of members of industry and the Air Force are absolutely vital. Here's hoping we succeed.

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AD-A152 733 PROCEEDINGS OF INDUSTRY/SPACE DIVISION/NASA CONFERENCE AND WORKSHOPS ON M..(U) SPACE DIV LOS ANGELES AFS CA 02 MAY 80 7/8

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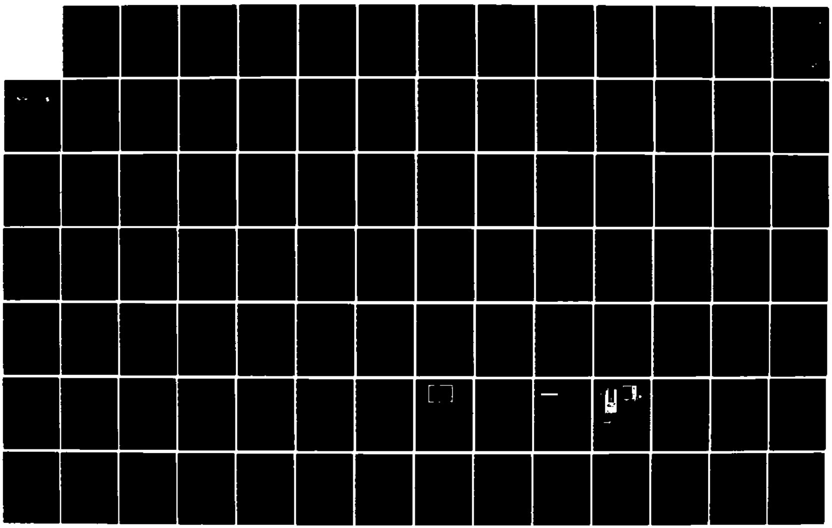

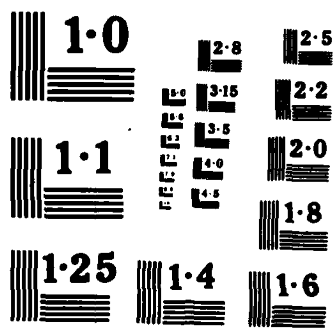
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AUTHORS' BIOGRAPHICAL SKETCHES

Captain David A. Herrelko is assigned to the Directorate of Computer Resource Development Policy & Planning, Deputy Chief of Staff for Plans and Programs, Air Force Systems Command. His previous assignments were with the Airborne Computer Engineering Branch, Deputy for Engineering, Aeronautical Systems Division, and with the Deputy for Control and Communication Systems, Electronic Systems Division. His primary experience is in real-time applications of computers in embedded weapon systems.

Captain Herrelko earned his BSEE degree from MIT in 1969, his MS in Systems and Information Science from Syracuse University, the MBA from the University of Dayton, and his Ph.D. in Engineering from UCLA in 1976.

Darryl Denton is currently fulfilling avionics systems engineering responsibilities with Northrop Corporation's Aircraft Division. He was previously a principal in the design and development of the real-time receiver control and signal processing software for NAVSTAR Global Positioning System prototype receivers built by Magnavox's Government and Industrial Electronics Company.

Mr. Denton holds a Bachelors and a Masters Degree in electrical engineering from Rice University.

SUMMARY OF ISSUES AND RECOMMENDATIONS

COMPUTER SOFTWARE

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Software Compliance Documents

Issue

On Air Force contracts there currently is no software contractural compliance document which provide the customer control over the software development process/ methodology.

Recommendations

o Establish DID for Software Management Plan (use NASA plan or example).

o Specify submittal/compliance requirement in RFP.

2. Standardization Initiatives

Issue

There is a high potential for reduced life cycle costs, less program risk, shorter development schedules and improved system support, through standardization initiatives. If standards are vendor and technology independent, Standard High Order Languages (HOL), computer set architectures multiplex data buses and common support systems can significantly improve our way of doing business if developed and applied using common sense in an open forum with industry.

Recommendations

o SD sponsor a study with a recognized association to determine applicability/exceptions of
  MIL-STD-1750A ISA
  MIL-STD-1589A Jovial (J73)
  MIL-STD-1553B Mux Bus
  Common system support facilities, industry critique and participation, and SD policy established.

3. Award Fee for Software

Issue

Award fee contracts are useful in controlling/rewarding excellence in software development and management.

Recommendations

o Develop award fee contract provisions emphasizing software computer system disciplines.

- design reviews
- configuration management
- quality assurance
- support systems development
- documentation
- performance
- timing & sizing
- growth

o Encourage their use.

o Develop evaluation tools for procurement use.

4. Software Quality Assurance

Issue

MIL-S-52779A has not produced the desired result:
- Contractor QA personnel not adequately trained in software.
- Procedures for software quality assurance program implementation. inadequate or non-existant.
- Software test tools not properly controlled.
- Lack or inadequacy of tailoring and enforcing of MIL-S-52779A by the government.

Recommendations

o Establish SD contractor qualification survey:
- Develop qualification criteria.
- Review contractor implementation procedures against criteria.
- Assess qualification level of SQA personnel.

- Adequacy of control of tools.

o Develop tailoring guides for MIL-S-52779A.

5. AFPRO Involvement

Issue

AFPRO role in software development/test/support unclear, vis-a-vis SPO.

AFPRO manning and training appear inadequate to meaningfully affect the software process or product.

Recommendations

o SD and AFCMD explore roles/mission re: SW management.

o Establish "master MOA" (SD-AFCMD)
  - state desired roles/missions
  - outline plan to match AFCMD manning and training with planned duties.

o Individual SPO/AFPRO MOAs
  - reflect intent of "master MOA"
  - recognize current AFPRO capabilities
  - adjust roles/missions accordingly

o Provide funding support for AFPRO training.

6. Software Skills

Issue

AFSC and SD critically short of competent aerospace software engineers/managers.

Problem getting worse - fast.

Recommendations

o Improve hygiene factors
  - pay
  - housing
  - promotions

o Train what you have.

o Institute AFSC/AFLC "job swap" program to prevent misassignment loss of specialists.

o Promote civilians to software management jobs.

o Increase Aerospace role.

7. Subcontractor Software

Issue

Problems in many cases have arisen from inadequate management of subcontracted software.

Recommendations

o Prior to contract award:
  - Ask officers to detail agreements prior to award.
  - Use pre-award survey for proposed subcontractors.
  - Attend subcontract awards.

8. Software Design Reviews

Issue

MIL-STD-1521 is too general.

Recommendations

o Develop criteria for tailoring MIL-STD-1521 for computer software.

9. Lack of Computer Specs.

Issue

Specifications and Data Item Descriptions (DIDs) do not adequately address requirements for very high speed computer systems (pipeline/parallel/signed processors).

Recommendations

o Working group to evaluate applicability of Specs and DIDs to very high speed computing systems.

o Recommend new or modified Specs/DIDs.

10. Procurement Practices

Issue

Contractor automation of the software development process allows production of cost effective documentation. SD procurement practices does not allow alternates to be proposed which could reduce costs and at the same time be more effective technically.

Recommendations

o Extend the concepts of MIL-S-83490, level c and SAMSO-STD-73-2c (on parts documentation savings) to software and develop the appropriate contractural language. Implement.

WORKSHOP J

REQUEST FOR PROPOSAL COMMUNICATIONS

Chairmen

Colonel Jim Russell
Director, Defense Systems
Contracts, AF Space Division

Neil Lamb,
Procurement Analyst
HQ NASA

Dick Pooch,
Director Acquisition Management,
Space Systems Division
Lockheed Missile And Space Co.

Coordinator

Dan Browne
AF Space Division

WORKSHOP PAPERS

Precontract Communications	Lt Col Ken Juvette, AFSD
Draft SOW/DRFP Effectiveness	Mr. Dick Pooch, LMSC SSD Mr. Bob Crossley, AFSD
RFP Preparation	Mr. Bob Cook, AFSD Mr. Jerry Madden, NASA GSFC
Proposal Preparation	Mr. Lou Gomberg, RCA ASTRO
Proposal Preparation	Mr. Tom Morris, RI SD
Proposal Preparation	Dr. Sam Silverberg, HAC
Proposal Evaluation	Mr. Joe Krueger, AFSD
Proposal Evaluation	Mr. Clen Neehan, HQ NASA

PRECONTRACT COMMUNICATIONS

Lt. Col. Ken Juvette, AFSD

SUBJECT: A CASE STUDY OF PRE CONTRACT INTERFACES

QUESTION: DOES THIS APPROACH CONTRIBUTE TO OVERALL MISSION ASSURANCE?

GPS CONTROL SEGMENT

CY

1979	1980	1981	1982	1983	1984	1985	1986	1987

GD/E (JAN 79–MAY 80)

MMC (JAN 79–MAY 80) — CONTROL SEGMENT – STAGE 2 WINNER (SEP 80 – MAR 87)

IBM (JAN 79–MAY 80)

LOGICON, INC. – IV&V (FEB 79–JUN 85)

COMPETITIVE ACQUISITION PLAN CONTROL SEGMENT

<u>STAGE I</u> PRE-DESIGN 17 MONTHS	• 3 PARALLEL CONTRACTS • FFP (LOE) • \$3.5M EACH	• COMPETITIVE DESIGN • COMMERCIAL EQUIPMENT
<u>STAGE II</u> FULL SCALE ENGINEERING/ DEPLOYMENT	• SINGLE CONTRACTOR • FPIF/AF • SHARE LINE 70/30 • CEILING-120% • (INCLUDING ALL OPTIONS AND AWARD FEE) 180M	• FULLY OPERATIONAL CONTROL SYSTEM • UPGRADE AND O&M OF Φ I SYSTEM

CASE STUDY-GPS OPERATIONAL CONTROL SYSTEM SEGMENT

• SELECTED SMALL (3-5 PEOPLE) DEDICATED PROGRAM OFFICE TEAM	SEP 77
• SYNOPSIZED FOR POTENTIAL PRIMES	SEP 77
• CONDUCTED CLOSED BUSINESS STRATEGY FORUM FOR CANDIDATE PRIMES	NOV 77
• DEVELOPED GOVERNMENT BUSINESS STRATEGY	DEC 77
• CONDUCTED OPEN FORUM FOR ALL INDUSTRY AND RELEASED GOVERNMENT'S REQUIREMENTS	JAN 78
• CONTRACTORS COMMENTS	FEB-MAR 78
• RELEASED DRFP	MAR 78
• CONTRACTORS COMMENTS	MAR-APR 78
• RELEASED FORMAL RFP	AUG 78*
• RECEIVED EXTREMELY COMPETITIVE PROPOSALS	SEP 78
• SELECTED THREE WINNERS FOR STAGE 1	DEC 78
• DESIGN REVIEWS	MAR-JUL-SEP-DEC 79
• DRAFT RFP STAGE 2	SEP 79
• GOVERNMENT/INDUSTRY PROCUREMENT REVIEW PANEL	DEC 79
• FORMAL RFP	MAR 80
• 3 MTH DELAY DUE TO HIGHER HQ COORDINATION PROBLEM	

CASE STUDY (1)

• PROGRAM OFFICE FORMS SMALL TEAM (3-5 PERSONNEL) TO WORK PENDING ACQUISITION	SEP 77
• CBD SYNOPOSIS DEVELOPED AND ISSUED	SEP 77
• 28 RESPONSES RECEIVED FROM INDUSTRY	OCT 77
• 13 CONTRACTORS DEEMED POTENTIAL PRIMES	OCT 77

CASE STUDY (2)

• PROGRAM OFFICE CONDUCTED CLOSED BUSINESS STRATEGY FOR 13 CANDIDATE PRIMES	NOV 77
• PROGRAM OFFICE REQUESTED PRIMES TO COME BACK IN TEN DAYS AND GIVE THEIR CORPORATE VIEW OF HOW BEST TO CONDUCT ACQUISITION	NOV 77
• NINE CONTRACTORS RESPONDED WITH BRIEFINGS	DEC 77

CASE STUDY (3)

- PROGRAM OFFICE DEVELOPED BUSINESS STRATEGY BASED ON CONTRACTOR INPUTS — DEC 77
- STRATEGY BRIEFED WITHIN GOVERNMENT — DEC 77
- CONDUCTED OPEN FORUM ON PROGRAM WITH ALL INTERESTED INDUSTRY PARTICIPANTS — JAN 78
- ALSO RELEASED TOP LEVEL GOVERNMENT REQUIREMENTS — JAN 78

CASE STUDY (4)

- RECEIVED CONTRACTOR COMMENTS — FEB & MAR 78
  - FORMAL
  - INFORMAL
- RELEASED DRAFT RFP — MAR 78
- RECEIVED COMMENTS — APR 78
- RELEASED FORMAL RFP — AUG 78 *
- THREE CONTRACTORS SELECTED FOR STAGE I — DEC 78

* 3 MONTH DELAY DUE TO HIGHER HEADQUARTERS COORDINATION PROBLEM

CASE STUDY (5)

- 3 CONTRACTORS IN COMPETITION FOR 15 MONTH DESIGN EFFORT — JAN 79
- CONTINUOUS INTERACTION WITH CONTRACTORS BOTH BUSINESS SIDE & TECHNICAL SIDE — JAN-DEC 79
- GOVERNMENT/INDUSTRY PROCUREMENT REVIEW PANEL — DEC 79
- FORMAL STAGE 2 RFP RELEASE — MAR 80
- EXPECT ANNOUNCEMENT OF WINNER — JUL 80

CASE STUDY
BENEFITS TO MISSION ASSURANCE

- NONE
- LITTLE
- MUCH

SUMMARY (1)

PROCESS — TOO SHORT / TOO LONG

EXPENSE — TOO LITTLE / TOO MUCH

SUMMARY (2)

REQUIREMENTS — TOO LOOSE / TOO DETAILED

TECHNICAL APPROACH — TOO MUCH LEVELING / TOO LITTLE LEVELING

SUGGESTED IMPROVEMENTS

A

B

C

D

COMMERCE BUSINESS DAILY

WHAT IS IT?

A DAILY LIST OF U.S. GOV'T ACQUISITION INVITATIONS/REQUESTS, CONTRACT AWARDS, SUBCONTRACTING LEADS, SALES OF SURPLUS PROPERTY, AND FOREIGN BUSINESS OPPORTUNITIES.

GENERAL POLICY
(DAR 1-1001)

"IT IS DOD POLICY TO INCREASE COMPETITION BY PUBLICIZING ACQUISITIONS WHICH OFFER COMPETITIVE OPPORTUNITIES FOR PROSPECTIVE PRIME CONTRACTORS OR SUBCONTRACTORS, THUS ASSISTING SMALL BUSINESS AND LABOR SURPLUS AREA CONCERNS AND BROADENING INDUSTRY PARTICIPATION IN DEFENSE ACQUISITION PROGRAMS."

RFP'S/IFB'S

CLEARLY INDICATE ANY QUALIFYING FACTORS AFFECTING THE ACQUISITION

- AVAILABILITY OF SPECIFICATIONS, PLANS, OR DRAWINGS
- COMPLETE DATA NOT AVAILABLE
- SECURITY REQUIREMENTS
- AVAILABILITY OF BACKGROUND RESEARCH REPORT
- PRODUCTION REQUIREMENTS
- STANDARDIZATION REQUIREMENTS

SYNOPSES

"DESCRIPTION SHALL BE CLEAR, CONCISE, AND IN SUCH DETAIL THAT IT WILL BE UNDERSTOOD BY POTENTIALLY INTERESTED PARTIES."

SYNOPSES OF PROPOSED ACQUISITIONS

- ACQUISITIONS IN EXCESS OF $10,000
- MODS TO EXISTING CONTRACTS WHEN NEW FUNDS ARE OBLIGATED
- PRE INVITATION/SOLICITATION NOTICES
- ADVANCE NOTICE OF AN AGENCY'S INTEREST IN A GIVEN FIELD OF R&D
- SOURCES SOUGHT, GOV'T INTEREST IN SPECIFIC R&D TASK

SYNOPSES IN CBD
3 TYPES

- OF PROPOSED ACQUISITIONS (DAR1-1003)
- OF SUBCONTRACT OPPORTUNITIES (DAR 1-1003.6)
- OF CONTRACT AWARDS (DAR 1-1005.1, 2-409)

ADVANCE NOTICE OF AN AGENCY'S INTEREST

A--LEASE/BUY ANALYSIS FOR STRATEGIC FORCES COMMUNICATION SATELLITE (STRATSAT) PROGRAM. THIS NOTICE IS ISSUED TO OBTAIN INDUSTRY'S COMMENTS OF THE POTENTIAL FOR THE USAF LEASING THE STRATSAT PROGRAM. THE USAF STRATSAT PROGRAM OFFICE HAS DEVELOPED A SET OF ASSUMPTIONS AND POSSIBLE HYBRID LEASING CONCEPTS THAT WILL BE USED IN THE ANALYSIS. INTERESTED FIRMS MAY REQUEST A COPY OF THE ASSUMPTIONS AND CONCEPTS FOR COMMENT ON THE REALISM OF THE PROGRAM FROM SPACE DIVISION NOT LATER THAN 15 DAYS AFTER PUBLICATION OF THIS NOTICE. SEE NOTE 99.

PROPOSED ACQUISITION
POSSIBLE SUBCONTRACTING OPPORTUNITIES

A--NAVSTAR GLOBAL POSITIONING SYSTEM (GPS) CONTROLLABLE RECEPTION PATTERN ANTENNA (CRPA) FLIGHT TEST PROGRAM. THE JOINT PROGRAM OFFICE FOR THE NAVSTAR GPS INTENDS TO CONDUCT NEGOTIATIONS WITH AIL DIVISION, CUTLER-HAMMER GROUP, EATON CORPORATION, COMAC ROAD, DEER PARK, LI, NY 11729 ON OR ABOUT 17 SEPTEMBER 79. SAMSO UP 79-17 APPLIES. THE CONTRACTOR WILL BE ASKED TO SUPPORT A C-141 CRPA FLIGHT TEST PROGRAM OF EQUIPMENT DELIVERED TO THE GOVERNMENT UNDER AN INDEPENDENT AIL IR&D EFFORT. THIS SYNOPSIS IS FOR INFORMATION AND PLANNING PURPOSES, DOES NOT CONSTITUTE AN IFB OR RFP, AND IS NOT TO BE CONSTRUED AS A COMMITMENT BY THE GOVERNMENT.

NOTICE OF CONTRACT AWARD

A--THE GOVERNMENT HAS AWARDED A CONTRACT TO ROCKWELL INTERNATIONAL CORP., 400 COLLINS ROAD NEW, CEDAR RAPIDS, IA (L) (F04701-78-C-0159/F04701-79-C-0083). THE CONTRACTOR WILL PROVIDE FULL SCALE ENGINEERING DEVELOPMENT FOR THE GLOBAL POSITIONING SYSTEM PHASE IIB USER EQUIPMENT AT A PRICE OF $88,105,714.00

MOD TO EXISTING CONTRACT

L--INDEPENDENT TEST AND EVALUATION SERVICES. NEGOTIATIONS WILL BE CONDUCTED FOR ADDITIONAL CONTRACT HOURS WITH LOGICON, INC., TORRANCE, CALIFORNIA. REQUEST FOR PROPOSAL (RFP) F04703-79-R-0034 APPLIES. SEE NOTE 46.

?

58--HIGH FREQUENCY RECEIVER -- 2 EA TO INCLUDE EXTENDER CARDS, TEST CORDS AND PECULIAR PLUGS REQUIRED TO ALIGN, TEST, AND MAINTAIN THE EQUIPMENT. SOLID STATE, MODULAR CONSTRUCTION, DIGITAL READOUT, MANUAL TUNING WITH CAPABILITY FOR REMOTE PROCESSOR OR MANUAL CONTROL. STANDARD EIA 19 IN. RACK MOUNTING. 115/230 VAC ± 10% FROM 47 TO 63 Hz. FREQUENCY RANGE .5 TO 30 MHz; MODES, CW, AM, LSB, AND USB. ESTIMATED RELEASE DATE OF IFB F04703-78-B-0005 IS 17 AUGUST 1978. THE AIR FORCE RESERVES THE RIGHT TO SET THIS PROCUREMENT ASIDE FOR SMALL BUSINESS BASED ON THE RESPONSES TO THIS SYNOPSIS. SEE NOTES 32, 56, AND 99.

DRAFT SOW/DRFP EFFECTIVENESS

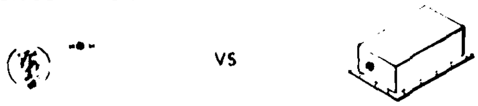
Mr. Dick Pooch, LMSC SSD

DRAFT SOW/RFP EFFECTIVENESS

- SPECIFYING THE REQUIREMENTS
- STRUCTURING THE SOW
- MOTIVATING THE CONTRACTORS
- MAXIMIZING MISSION ASSURANCE BENEFITS

SPECIFYING THE REQUIREMENTS

- MISSION DEFINITION



- TRADEABLE REQUIREMENTS
  - PERFORMANCE
  - SCHEDULE
  - COST
  - RISK
- MUSTS VS WANTS

SPECIFYING THE REQUIREMENTS (CONT.)

- ZERO BASE SPECIFICATIONS
  - WHO SPECIFIES?
  - CONTRACTOR UNIQUE SPECIFICATIONS
- SPECIFICATION TAILORING
  - PRE VS POST RFP (SOURCE EVALUATION PROBLEMS)
  - COST AVOIDANCE POTENTIAL
- SPECIFICATION PYRAMIDS
  - PRODUCT (LEVELS MAXIMUM)
  - MIL SPECS STANDARDS (TIP OF THE ICEBERG)
- CONTENT DISCIPLINE
  - SECTION 3 TECHNICAL ONLY
  - AVOID MANAGEMENT PROCUREMENT SOW CDRL REQUIREMENTS BURIED IN TECHNICAL SPECIFICATIONS

SPECIFYING THE REQUIREMENTS (CONT.)

- EXECUTIVE SUMMARY HIGHLIGHTS OBJECTIVES PRIORITIES CONCERNS AND CONSTRAINTS
- PROVIDE RATIONALE FOR REQUIREMENTS
  - GOVERNMENT STUDIES ANALYSES AND TESTS
  - CONSULTANT OUTPUT

STRUCTURING THE SOW

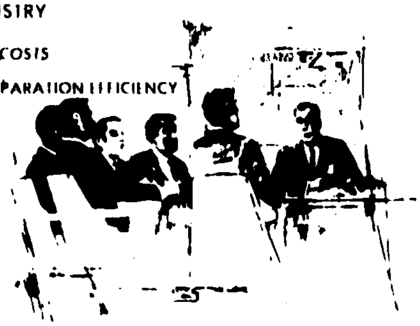
- OBJECTIVES VS TASKS
- WHAT VS HOW
- LEVEL OF DETAIL
- GOVERNMENT VS CONTRACTOR GENERATION
- WBS TRACEABILITY
- MIL SPECS/STANDARDS/CDRLS

MOTIVATING THE CONTRACTORS

- INDUSTRY REVIEW COMMENT CYCLE
  - TURNAROUND SCHEDULE
  - GROUND RULES FORMAT CONSTRAINTS
  - WRITTEN VS ORAL
  - GOVERNMENT INDUSTRY MURDER BOARD

MOTIVATING THE CONTRACTORS

- PROPRIETARY DATA PROTECTION
  - DISSEMINATION OF COMMENTS RECOMMENDATIONS
  - INCORPORATING COMMENTS IN THE RFP
- COSTS TO INDUSTRY
  - REVIEW CYCLE COSTS
  - PROPOSAL PREPARATION EFFICIENCY



MOTIVATING THE CONTRACTORS (CONT.)

- INCENTIVIZING CONTRACTORS
  - EARLY, DETAILED EVALUATION CRITERIA
  - EVALUATION POINT BONUS
  - FAVORABLE INTERCHANGE ENVIRONMENT
  - COST REIMBURSEMENT CONSIDERATIONS
  - ACCOMMODATION FOR INNOVATIONS (AVOIDING ALTERNATE PROPOSALS)
  - GOVERNMENT FEEDBACK
  - EVIDENCE OF GOVERNMENT ACCEPTANCE

MAXIMIZING MISSION ASSURANCE BENEFITS

- EARLY REQUIREMENTS DISSEMINATION
- MAXIMIZE CONTRACTOR DEFINITION RESPONSIBILITY UNIQUE SPECS
- ENCOURAGE PERFORMANCE COST RISK REQUIREMENTS AND CONCEPT TRADES

MAXIMIZING MISSION ASSURANCE BENEFITS (CONT)

- MAXIMIZE OPEN GOVERNMENT CONTRACTOR INTERCHANGE THROUGHOUT PROCESS
- PROTECT PROPRIETARY INFORMATION
- PROVIDE VISIBILITY AND FEEDBACK OF UTILIZATION OF CONTRACTOR INPUT

DRAFT SOW/DRFP EFFECTIVENESS

Robert J. Crossley
Procuring Contracting Officer
Air Force Space Division

1. My presentation is based on my experience at Space Division and does not necessarily reflect the procedures used at any other Government buying office. As a matter of fact these procedures are not always used at Space Division; they vary depending on value, source selection/selected source, and urgency of the acquisition. While we do have a rather structured procedure we also have a degree of flexibility, so that all procurement situations can be accommodated. It would take forever to discuss all of the "what if" procurement situations, so I'm presenting the framework of our review procedures for a typical competitive acquisition valued at over $10M with particular emphasis on the draft RFP considerations.

2. Let me give you a one or two line description of each review and return to the draft RFP.

3. Requirement Review

O PMD - General direction to a buying command telling it to go accomplish a broad objective.

O Acquisition Plan - prepared by the buying command by way of a reply to the PMD; states how the objective is to be attained.

O SOW - Statement of the Government's need; may be general or specific depending on the phase of the acquisition.

O G In-House SOW Review - A review by functional specialist to assure applicable directives have been considered.

O DRFP - May be a complete or partial version of the final RFP. Intended to be a means of having industry participate in defining Government requirements.

O G In-House Review - Consolidates industry comments into a final RFP, includes a source selection board review.

O G Murder Board - Chaired by senior procurement staff personnel. Membership includes legal, administrative, financial and functional specialists. This is a page by page review of the entire RFP.

O RFP Changes - Usually issued prior to receipt of proposals but may be after.

4. Now then, returning to the draft RFP procedures. A draft must be sent out on virtually all acquisitions whether they are sole sourced or competed. Prior to its release the draft undergoes an abbreviated procurement staff review to assure that it is at least generally compliant with existing directives. Without this review the draft and final might appear to be for completely different requirements. With the review there is some assurance that all the "ilities", human, safety, and other factors appear in the draft as they are proposed to appear in the final.

5. Draft RFPs are then sent to all firms on the source list; the source list being made up of firms that responded to a "sources sought" synopsis.

6. Industry comments are reviewed by functional specialists within the Government and a record made of the disposition of each comment (accepted, rejected, modified, etc.). Comments are not usually discussed with the submitters because it would take an awful lot of time. About the only thing a submitter gets is a letter acknowledging receipt of the comments. This minimal feedback is a "soft spot" in the DRFP procedure since significant comments could be rejected because of the way they are written. However, the submitter may get three more chances to present the comment; at a pre-soliciation conference, a pre-proposal conference, and at discussions prior to submitting a best and final offer. Now, if a submitter really wants to crusade, the comment could be submitted as part of an alternate proposal.

7. Another "soft spot" in the DRFP procedure is the need for a firm to stradle a line between trying to influence a solicitation by submitting DRFP comments and compromising its competitive position. Whatever incentive there is to

submit comments must be self-generated by the firm itself, since the Government doesn't offer much. As a matter of fact, the Government has its own version of the contractor's dilemma; specifically, the Government has a much larger stake in preserving the competition then it does in receiving DRFP comments, yet comments are solicited.

8. Ideally DRFP comments represent a meaningful compromise with industry and the Government keeping competition as an overriding concern.

9. I'm not in a position to comment on the overall effectiveness of the Government's DRFP initiatives, however on the programs I've been associated with, the DRFP effort has been worthwhile. As a minimum, it is a communications medium that allows firms to derive an early bid/no bid position. Some comments are incorporated into the final RFP, these include contract line item structuring to facilitate payments; Government property requirements, CDRL and specification tailoring. One of the larger benefits is the identification of ambiguities in the solicitation that can be cleared up in the final.

10. To the extent the DRFP procedures contribute to Government requirements being clearly communicated to industry, they are worthwhile; they lose value to the extent they compromise competition or lengthen the acquisition cycle. I don't know of any situation where these negative concerns have materialized so in my view the DRFP initiatives have producing positive results. Even these results could be improved if the Government could stimulate greater industry participation. In my view formulating the stimulant will prove to be a noble endeavor because of the subjective judgments that would have to be documented almost to the point of demonstrating that there was no subjectivity involved and the very limited one-on-one dialogue that is permitted during a source selection.

11. Leaving the DRFP, I'd like to give you a few words on how the Government structures their Statement of Work.

12. <u>Strucutre of SOW</u>

0 State the Objective - The degree to which requirements are defined depends on the stage of the acquisition. For the conceptual stage relatively broad objectives are defined; for the production stage the objectives are rather explicit.

0 Government Vs Contractor Generated - The practice of incorporating a contractor's proposal or other document by reference into the RFP or the contract as the SOW is not condoned and will be discontinued.

0 Level of Detail - SOWs often have to be read and interpreted by persons of varied backgrounds such as lawyers, buyers, engineers, cost estimators, accountant, and functional specialists in production, transportation, security, audit, quality control and contract managers.

0 Traceability to WBS - Although desirable it depends on the particular program. Multi-service participation may influence WBS.

0 What To Do Vs How To Do It - Supply acquisitions demand definable physical or performance descriptions of end products. R&D acquisitions should be definitive enough to protect the Government's interest, yet broad enough to allow for the contractor's creative effort.

0 Inclusion of CDRLs and Reporting - Contract data or reporting requirements should not be duplicated in the SOW. DD 1423 is the medium for establishing data requirements.

13. Thank you.

SPACE DIVISION RFP PREPARATION

ROBERT G. COOK

DSCS II Systems Effectiveness Manager

This presentation is intended to show the Mission Assurance requirements normally included in Air Force Space Division Request for Proposals. These requirements are differentiated from the technical performance requirements and are loosely grouped under the term System Effectiveness. I intend to show the Space Division philosophy toward the Request for Proposal, outline the requirements and directives which govern preparation of the RFP and show the internal processing drafts of the RFP receive before they are formally issued. Then I will discuss the outline of the RFP and within that outline show where the principal System Effectiveness requirements are located. These requirements are not really hidden but frequently there is a tendency to only look for requirements within the statement of work or the compliance documents. Lastly, I want to show what the source selection evaluation team is looking for in the proposal itself and point to some problems we have experienced in the RFP-Proposal cycle and request suggestions to reduce their impact.

To begin we must define what is generally meant by system effectiveness. The contract requirements shown on this slide (3) are the principal tasks normally grouped under the systems effectiveness label. Some people add and some subtract from this list but generally it covers the ground. These are the requirements which we will attempt to locate in the RFP.

The government objectives for an RFP are shown on this slide (4). It is important to recognize that the RFP is a means to accomplish an end, not an end in itself. Contrary to popular belief, it's objective is not to 'trap' a contractor into financing the United States Government either. It is supposed to be a simple statement of the government's needs and directions on how to bid in an acceptable manner to supply those supplies and services to the government. The primary purpose is the last item on the chart "meaningful negotiations". Contracts require a mutual understanding of the requirements and the methods expected to be applied in achieving requirements. Negotiations is the work expended in mutually understanding the scope of work to be accomplished. Effort spent during this stage of the program avoids almost continual confrontations over interpretations of requirements later in the program.

Space Division policy since 1977 has emphasized the importance of mission success. Evaluation factors in the past, while requiring evaluation of quality, did not require formal mention of quality in the briefing to the source selection authority. Now the perception of quality is a vital factor in source selection and it must be discussed in every source selection briefing. This is tacit recognizition that simply building a space system which works is no longer a major problem, the significant problem is to build a system which works over a long term and provides continuous service.

The directives on this slide (6) are the primary source documents for planning and structuring the request for proposal. The preparation guide not only lays out the required content of the RFP: it provides an excellent outline of the Proposal instructions including a suggested table of contents. The pamphlets on statement of work preparation are also useful guides. Since the overall purpose of the RFP is source selection, I also show those requirements here because any RFP must require the information necessary to make a source selection decision.

Chart 7 is a very abbreviated flow chart of the RFP cycle. The background information is digested and separated into contractor and government activities. When the contractor work is determined, the RFP generation cycle usually starts with a Contracting officer and a Project officer drafting the required documentation, one of which is the Request for Proposal. A tremendous amount of coordination is required during the RFP drafting effort as all interested parties provide input information and comments for incorporation. It is really up to the project officer to assure that these com-

ments fit the RFP and form a unified and understandable document. After preparation of the initial drafts, coordination with industry may be solicited and review by a number of panels occurs. These reviews are usually very detailed and agreement must be reached before release of the RFP is allowed. This cycle is extremely long and time consuming and in many cases the panels provide conflicting advice which must be resolved. The current trend in procurement appears to be to add more review cycles to this list, not less.

An outline of the RFP is shown in the next slide. I will discuss each of these parts and show their system effectiveness requirements. This outline was changed recently. The General Instructions section, Part IV, was originally Part I. The current Part I, II, and III constitute the model contract portion of the RFP. This section, with all the blanks completed eventually becomes the contract and should contain all the government requirements. The contractors proposal in the form of plans is usually added to part four to commit the contractor to do the work he proposed and on which he based his costs.

Where are the requirements? They are well distributed throughout the RFP. The Schedule documents the items shown. Its principal feature is the identification of deliverable products and services and definition of how and when the government intends to verify that the product or service conforms to the requirement. The General Provisions of the contract contain those standard DAR clauses which apply. There is occasionally some duplication of these clauses with the statement of work - notably Mil-Q-9858 is normally cited as a requirement in both.

The main system effectiveness requirements are in part III. Here the Statement of Work tasks are referenced including the compliance documents. Deliverable data is identified and described in detail and the specification of requirements is referenced. Mil-Std-454 specification requirements for space vehicles is tailored by Mil-E-8983B. The compliance document list of the statement of work is where most management system requirements are invoked Space Division directives are very clear about the need for tailoring of compliance documents, and only using those portions which are necessary for the procurement. Tailoring should be documented along with the document call-out on the list. It is usually not sufficient or acceptable to tailor requirement documents in the contractors proposal or plans. Contractor input to the tailoring process is desireable and usually solicited by issuing "draft" RFPs for industry coordination. The chart (12) lists some of the compliance documents which normally appear on SD Requests for Proposals.

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Since a proposal is the intended end result of the RFP it is worthwhile to consider what response the government expects to it's RFP.

First, of course, the government expects the contractor to identify his approach in sufficient detail so that the risks involved in the approach can be fully evaluated.

Second, the government expects the proposal to be sufficiently complete to determine the work tasks to be performed by the contractor. The government needs this data to understand the scope of the work proposed and the cost basis of the contractor's proposal. It also supports realistic estimates of contract schedule and the related risks.

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The proposal is required to contain de-

tailed work plans. These plans are not intended to be a rehash of the compliance documents but detailed work plans describing who will do what work, when that work will be done, and the methods and number of people intended to work the task. It is amazing that most proposals do not use this simple approach to planning. If this plan goes into sufficient detail there will be no question about the intentions or understanding of the requirements by the contractor. When the proposal plans are written in this straightforward fashion the negotiation effort is reduced because both parties will understand what work is to be done.

The last chart (16) lists some examples of perceived problems with RFPs. Most of these problems will never go away completely, but work to reduce the irritation level would certainly be useful.

AGENDA

WHERE ARE SYSTEM EFFECTIVENESS REQUIREMENTS IN RFP?

WHAT RESPONSE DOES THE GOVERNMENT EXPECT?

PROBLEMS EXPERIENCED.

SETTING THE STAGE

SYSTEM EFFECTIVENESS IS A SYNTHESIS OF THE CONTRACTING "ILITIES"

- RELIABILITY
- PRODUCIBILITY
- MAINTAINABILITY
- OPERABILITY
- QUALITY

REQUEST FOR PROPOSAL OBJECTIVE

"SOLICIT PROPOSALS FOR REQUIRED SUPPLIES AND SERVICES FROM INDUSTRY."

"KEY COMMUNICATION TO POTENTIAL CONTRACTORS ON EXACTLY WHAT, HOW, AND WHEN THE GOVERNMENT NEEDS TO BUY"

PROVIDE A VEHICLE TO "FOSTER MEANINGFUL NEGOTIATIONS"

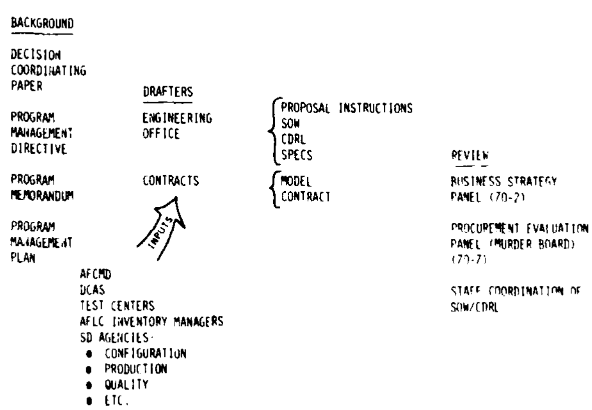
SPACE DIVISION POLICY

"WHILE MANY FACTORS MUST BE CONSIDERED DURING THE SELECTION PROCESS, QUALITY ASSURANCE (QA) MUST BE INCLUDED SINCE IT IS MOST VITAL TO MISSION SUCCESS. IT IS FITTING, THEREFORE, THAT THE EVALUATION FACTORS FOR AWARD IN ALL SOURCE SELECTION PLANS AND COMPETITIVE SOLICITATIONS CLEARLY SET FORTH THIS DOMINANT REQUIREMENT AS AN AWARD CONSIDERATION."

DIRECTIVES RELATED TO RFP PREPARATION

- AFSC PAMPHLET 70-4
  "REQUEST FOR PROPOSAL PREPARATION GUIDE"
- AF REGULATION 70-15
  "SOURCE SELECTION POLICY AND PROCEDURES"
- AFSC REGULATION 70-15
  "SOURCE SELECTION POLICY AND PROCEDURES"
- AFSC PAMPHLET 800-6
  "STATEMENT OF WORK PREPARATION GUIDE"
- SPACE DIVISION PAMPHLET 800-6
  "STATEMENT OF WORK PREPARATION GUIDE"

THE RFP PREPARATION CYCLE



CONTENT OF THE RFP

- PART I - THE SCHEDULE
  SUPPLIES, SERVICES AND PRICES
  DESCRIPTION/SPECIFICATIONS
  PRESERVATION/PACKAGING/PACKING
  DELIVERIES ON PERFORMANCE
  INSPECTION AND ACCEPTANCE
  SPECIAL PROVISIONS
  CONTRACT ADMINISTRATION DATA
- PART II - GENERAL PROVISIONS
  GENERAL PROVISIONS
- PART III - LIST OF DOCUMENTS AND ATTACHMENTS
  STATEMENT OF WORK
  COMPLIANCE DOCUMENTS
  CDRL
- PART IV - GENERAL INSTRUCTIONS
  COVER SHEET
  CONTRACT FORMS, REPRESENTATIONS AND CERTIFICATIONS
  SOLICITATIONS INSTRUCTIONS CONDITIONS AND NOTICE TO OFFERS
  EVALUATION FACTORS

WHERE ARE THE REQUIREMENTS?

PART I THE SCHEDULE

- IDENTIFIES ITEMS TO BE DELIVERED

  INCLUDES SITE CODES FOR PQA/ACP/FOB.

- IDENTIFIES PRICE AND DELIVERY DATES.

- INSPECTION, ACCEPTANCE AND FOB POINT

  DEFINES GOVERNMENT PARTICIPATION IN INSPECTION AND ACCEPTANCE ACTIVITY.

WHERE ARE THE REQUIREMENTS?

PART II - GENERAL PROVISIONS

- STANDARD OF WORK	7-302.2
- INSPECTION CLAUSES	7-302.4(A) 7-302.4(B)
- MATERIAL INSPECTION & RECEIVING REPORT	7-104.62
- QUALITY PROGRAM	7-104.28
- CERTIFICATE OF CONFORMANCE	7-104.100

WHERE ARE THE REQUIREMENTS?

PART III LIST OF DOCUMENTS, EXHIBITS AND OTHER ATTACHMENTS

- STATEMENT OF WORK
  - PARAGRAPH 3: CONTRACTOR TASKS
    - 3.1 COMPLIANCE DOCUMENTS
    - 3.X OTHER TASKS
  - PARAGRAPH 4: SPECIAL CONSIDERATIONS
- CDRL
  - PLANS & UPDATES
  - SPECIFICATIONS
  - FAILURE/DEFICIENCY REPORTS
  - TEST PLANS/PROCEDURES/REPORTS
- SYSTEM SPECIFICATIONS
  - SPECIFIC HARDWARE REQUIREMENTS USUALLY FROM MIL-STD-454

WHERE ARE THE REQUIREMENTS?

COMPLIANCE DOCUMENTS OF SOW

- SAMSO STD 73-2 ELECTRONIC PARTS, MATERIALS AND PROCESSES FOR SPACE AND MISSILE APPLICATIONS:STD CONTROL PROGRAM
- SAMSO STD 73-5 SPECIAL QUALITY ASSURANCE REQUIREMENTS FOR SPACECRAFT AND MISSILE SYSTEMS
- MIL-STD-1520 CORRECTIVE ACTION AND DISPOSITION SYSTEM FOR NON CONFORMING MATERIAL
- MIL-STD-1543
- MIL-Q-9858
- MIL-S-52779
- CONTRACTOR PLANS

WHERE ARE THE REQUIREMENTS?

PART IV GENERAL INSTRUCTIONS

- BACKGROUND OF PROGRAM
- PROPOSAL FORMAT

  WHAT PLANS ARE REQUIRED?
  WHAT ANALYSIS IS REQUIRED?
  HOW COSTS ARE TO BE STATED
- EVALUATION FACTORS

  IDENTIFIES EVALUATION BREAKOUT AREAS, ITEMS, FACTORS.
  IDENTIFIES CRITERIA ADEQUACY/DEFINITIVENESS, CLARITY/COMPLETENESS.
  IDENTIFIES RELATIVE RANKING.

WHAT RESPONSE IS EXPECTED?

PROPOSAL WHICH ADDRESSES EACH OF THE 'ILITY' REQUIREMENTS

- IDENTIFY AREAS OF TECHNICAL RISK
- METHODS TO REDUCE RISK
- TIMETABLE FOR DECISION

PROPOSAL SHOULD CONTAIN DETAILED PLANS

- EXPLAIN THE MANAGEMENT OF THE TASK
- WHO DOES WHAT
- HOW WORK WILL BE DONE (METHODS/EXTENT)
- WHEN WORK WILL BE DONE
- SUPPORTED BY COST ANALYSIS
- DO NOT RESTATE REQUIREMENTS

WHAT RESPONSE IS EXPECTED?

PROPOSAL WHICH PROVIDES A MEANS FOR CONTRACT DEFINITIZATION

- DEMONSTRATES UNDERSTANDING OF REQUIREMENTS
- DEFINES WORK CONTRACTOR WILL PERFORM
- SUPPORTS A "FAIR EXCHANGE"

PROBLEMS EXPERIENCED

GOVERNMENT REQUIREMENTS LIMIT CONTRACTOR OPTIONS. (SPECS AND STANDARDS)

MANAGEMENT DOCUMENTS CHANGE SO FAST EACH CONTRACT IS "NEW BALL GAME".

CONTRACTOR PROPOSALS DO NOTHING MORE THAN REPEAT REQUIREMENTS FROM RFP.

COST PROPOSALS DO NOT SUPPORT TASKS PROPOSED.

EVALUATION OF PROPOSALS IS IMPAIRED BY FAILURE TO CONSIDER EVALUATION IN FORMATING.

PREPROPOSAL PAPER

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1. Introduction

This paper will deal with the contents of Request for Proposals (RFP) for Space Transportation System (STS) payloads from the Goddard Space Flight Center (GSFC). The STS defines a payload as an equipment or material carried by the STS that is not considered part of the basic STS itself, including items such as free-flying automated spacecraft, coherent experiment units, individual experiments and instruments. In general, such payloads are going to be procured using a two phase approach where the first phase calls for a study proposal and the second phase calls for an implementation proposal. In the study phase, one or more proposals are accepted. An RFP for a one proposal approach would be similar to an RFP issued in Phase-II of a two phase approach.

In general, for large procurements, NASA Management Instruction (NMI) 1700.14A (Major Ssytem Acquisition) will be used. This is NASA's implementation of the Office of Management (OMB) Circular A-109. The author is most familiar with the Gamma Ray Observatory (GRO) procurement, and in most instances will be basing his remarks on this particular experience.

2. Early Briefings

Normally the call for scientific instrument proposals precedes the release of an RFP for a prime or mission contractor by several months to a few years. The Announcement of Opportunity (AO) gives general information about the program's plans and objectives. An AO gives general orbit and spacecraft characteristics as well as a description of the evaluation, selection and acquisition processes. It alerts industry to NASA's intent to proceed with the program.

When possible, NASA will brief industry on its upcoming missions. This is done to arouse interest in and to explain programs being planned. The briefing gives the goals of the program and informs potential proposers for the mission what the program constraints are likely to be. The NASA 5 year plan is one of the major documents that advises industry. On the GRO program, an industry briefing was arranged after the selection of the scientific instruments. This alerted industry to the needs of the scientific instrumenters and what portion of their work was open to industrial competition. It gave industry an idea of the physical requirements needed by a spacecraft to support this complement of instruments.

3. Study Phase RFP

a. General

The basic idea of the study phase is to limit the government input to the mandatory constraints so that the proposers will have a maximum flexibility in their proposals. In most cases within NASA, the mandatory constraints essentially limit the response of a proposer to variations on a known solution or a fixed concept. The proposer does have the opportunity to be innovative in his approach, his implementation scheme, his operational plans, and his cost control methods. The Mission Need Statement that is signed by the NASA Administrator outlines the major constraints for a procurement. The normal constraints given by the Mission Need Statement are: (1) a spacecraft is required to do the mission, (2) the Shuttle must be used as the launch vehicle, (3) data collection, reduction and analysis should be done using existing facilities to the extent possible, and (4) the payload (scientific or application instruments) will be obtained using an AO and be Government Furnished Equipment (GFE) to the proposer or the instruments are to be furnished by the prime or mission contractor. These constraints determine the parameters for the spacecraft, the characteristics of the communication system and the form of the data reduction and analysis. The proposers are given this conceptual skelton on which they must build their responses to an RFP. In many NASA procurements the basic concept is set by the constraints. What is sought using the NMI 1700.14A is

a better idea for the overall approach and the most economical use of the resources available to do the mission.

b. Content of the Study Phase RFP

The study RFP is designed to contain information on the constraints, a simple Statement of Work, a general set of evaluation criteria and a small list of deliverables. Evaluation criteria will not be discussed.

(1) Constraints

At the present time proposers must spend a good deal of time determining the Shuttle, the Tracking and Data and Relay Satellite System (TDRSS) and the ground communications requirements since some of these systems are presently in the development phase. In a few years the handling of reqirements using these systems will become routine. The present day RFP will reference the users manual for these systems. The proposers will be expected to know the content of these manuals and any peculiarity of these systems which might affect the implementation of his ideas.

The instrument payload documentation or a straw instrument payload description is normally furnished as part of the data package of an RFP since this infomation is specific to the RFP and not general public knowledge. General documents such as various user guides or parts lists are referenced since they are public documents. The payload instrumentation requirements and the TDRSS and STS User Handbook establish the general characteristics that a spacecraft and ground system must pessess. There will be some trade-offs between the spacecraft and the ground system left to the discretion of a proposer, however, bounds on such items as spacecraft power, thermal design, pointing accuracy, bit rates, operations controls, magentic restraint and ground systems response time, and user accommodations will be set.

(2) Statement of Work

The Statement of Work (Attachment 1) is written to give maximum flexibility to the proposer. It provides information not found in the constraints (e.g., spacecraft life and classification (NMI 8010 dated 9/26/79 "Classification of NASA STS Payloads")), gives a general statement of what the mission is and states what the output of the study is to be (e.g., functional specifications for the systems and subsystems).

(3) Deliverables

The list of deliverables is held to the minimum so that maximum amount of resources can be spent on the study itself. A mid-term report and final study report are usually required. Study contracts are normally fixed price; therefore, no financial reporting is required.

c. Product Assurance

Two items that NASA will pay more and more attention to are the value returned for the value invested and customer (scientific community, NASA, etc.) satisfaction. An overall approach is desired--one that satisfies the real purpose of the mission, i.e., delivers the proper data to the appropriate user in a timely manner. This focus on the end product has resulted in a very high level of confidence being required of the ground system.

Flight systems are expected to work. After 20 years of experience, first flight units are now being considered part of an operational system rather than test vehicles. Large data handling and communication systems have reached maturity. The main difficulty in the past has been the fragmented approach where emphasis shifts from the flight hardware and software to the data operational hardware and software almost as a step function. Now one wants a thorough detailed plan for achieving the final objective, i.e., getting the data to the user. This plan should be started in the study phase and permeate the planning of the implementation phase. The stating of the classification of the payload in the RFP informs the proposers of approximately what level of quality assurance will be required, what reviews are to be held and what documentation will be required. This payload classification

system is new and most of the implementing documentation is in the formative state. The documentation should be available by the latter part of 1980.

4. Implementation Phase RFP

a. General

The GSFC approach to the implementation phase RFP is to use general functional specifications for the mission and let the proposer respond with specific functional specifications for the systems and subsystems. The goal is to give the proposer the greatest degree of freedom possible in his proposal. The RFP does get specific in the quality assurance requirements, external interface requirements, and financial and progress reporting requirements.

b. Content of the Implementation Phase RFP

The implementation phase RFP contains a detailed Statement of Work, a detailed list of mandatory interfaces, a list of quality assurance documents a specific set of evaluation criteria and a detailed list of deliverables. Evaluation criteria will not be discussed.

(1) Constraints

The interface and quality assurance documents are the real specifications for the work to be done and are the constraints for this RFP. These documents establish the major constraints in detail and limit a proposer to a definite set of rules governing his overall plans.

The payload interfaces set the basic requirements for the spacecraft and ground system design. The launch vehicle requirements, including the methods used to determine tariff, will drive the mechanical design and operational plans. The communication link interfaces will determine the major specification for data handling systems for both the spacecraft and the ground systems. The quality assurance documents will state how the systems are to be built, tested and operated to assure success.

(2) Statement of Work

The Statement of Work for the implementation phase RFP is essentially a list of all the tasks to be performed and the work to be accomplished under each task (Attachment 2. a page excerpt from the Earth Radiation Budget Satellite RFP). Each task is defined by a general statemnt and a statement of responsibilities. These inform the proposer that he is responsible for all work to be done to accomplish the task even if such work is not specifically stated. One of the primary purposes of the Statement of Work is to define in concise and clear terms the responsibilities of all parties. This is normally done by using rules of exception, i.e., the proposer is responsible unless specifically told that he is not responsible. The Statement of Work takes about 20 to 30 pages. It consists mainly of very short, one line descriptive sentences.

(3) Deliverables

This will be a detailed list of all items needed. An attempt will be made to limit the type and amount of reporting, technical documentation and other items to conserve resources.

c. Product Assurance

The role of the Source Evaluation Board (SEB), the Technical Advisory Committee (TAC), and the Business Management Committee (BMC) in a two phase procurement under NMI 1700.14A is not only to prepare the RFP and evaluate the proposal but to monitor the work being done under the study phase.

One goal of NASA is to maximize the utility of its resources. Each new major space mission requires significant resources and a failure of a mission would probably result in putting the mission back to the starting point of justifying its existence. It is very important that every effort be made to have a successful mission consistent with the guidelines issued in the classification of NASA Shuttle payloads (Attachment 3, a very preliminary sample of STS Minimum Assurance Requirements).

STATEMENT OF WORK FOR THE SYSTEMS DESIGN CONCEPT STUDIES FOR THE GAMMA RAY OBSERVATORY

I. Scope

This Statement of Work covers the procurement of the study phase (Phase I) of a two-phase procurement of the Gamma Ray Observatory (GRO) in accordance with the Office of Management and Budget Circular No. A-109 and implemented by NASA Management Instruction (NMI) 7100.14A dated April 19, 1978. In the study phase, the contractor is to present his concepts for the GRO mission.

II. Gamma Ray Observatory System Baseline Requirements

The GRO system consists of two segments: the free flyer segment and the ground segment. The contractor is responsible for all the free flyer hardware and software except the scientific instruments hardware and software which will be Government Furnished Equipment (GFE). The contractor is responsible for all the mission unique ground segment hardware and software required to support the free flyer segment from inception to the end of mission life except the scientific instruments ground support systems which will be GFE.

The free flyer segment is to be launched by the Shuttle into a near circular orbit. The free flyer will have a 2-year mission life. The free flyer will be capable of being retrievable. The free flyer segment must be compatible with the TDRSS, the Shuttle, the NASA ground systems, and the five scientific instruments listed below:

1. 0.1-10 MeV Gamma Ray Instrument--Naval Research Lab, Dr. Kurfess
2. Compton Telescoper Instrument--Max-Planck-Institute, Dr. Schonfelder
3. Gamma-Ray Spectroscopy Instrument--Univ of Calif, San Diego, Dr. Peterson
4. High Energy Gamma-Ray Telescope Instrument--Goddard Space Flight Center, Dr. Fichtel
5. Gamma-Ray Burst Instrument--Marshall Space Flight Center, Dr. Fishman

The ground segment consists of all mechanical, electrical, and software systems required to support the free flyer segment during construction, integration, test, and pre and post-launch operations. The contractor will operate the spacecraft in orbit.

Attachment 1

STATEMENT OF WORK (Cont'd)

III. Phase I Definition

Statement of Work

In the system design concept study, the contractor is to develop his proposed mission concept and explain how it satisfies the objectives of the GRO mission. He is to illustrate how each individual segment of his concept fits into the overall plan to satisfy the mission's needs and how he would economically apply the resources to minimize duplication of effort and reduce costs in the hardware, software, and operational phases of overall concept. He will perform the necessary analyses and trade-off studies needed to demonstrate the validity of his concept.

The contractor is to refine his concept of the flight segment. He is to illustrate his approaches to handling all external interfaces, such as the scientific interfaces, the STS, the TDRSS, and the POCCNET. He is to define his general test plan, safety plan, and quality assurance plan outlining the detailed content he intends to develop for the actual implementation. He is to discuss the studies he has done to validate his concept and outline additional studies and/or trade-offs he plans for the execution phase and how he plans to make the free flyer retrievable.

The contractor is to explain how he intends to implement the ground segment of the GRO mission. His general plan to use the ground segment hardware, software, and procedures during integration, test, prelaunch operations, launch, and post-launch operations is to be explained. He is to explain both the capabilities and the limitations of his proposed ground segment. He is to show how this segment meets the overall mission needs.

Alternates

The contractor is to make recommendations regarding the desirability or lack thereof of for (1) servicing the Observatory in orbit, (2) refurbishing the Observatory in orbit, and (3) providing controlled re-entry of the observatory without use of the shuttle.

He is free to propose other alternates which he feels will enhance the mission, either through greater scientific return or significant cost benefit to the government.

3.3 SPACE SEGMENT REQUIREMENTS

3.3.1 System Engineering

The contractor shall perform all systems engineering tasks required for the successful performance of the mission, including, but not limited to, the following:

a. Analysis and formulation of the overall system performance compatibility, interactions, and margins requirements.

b. Develop design requirement specifications for system, subsystems, and components.

c. Analyses to verify subsystem performance, such as thermal analysis, structural analysis, control system computer simulations, energy balance capability; also parametric studies directed toward minimization of instrument loads and stresses.

d. System design verifications, including STS safety requirements verification.

e. Evaluation of technical adequacy of systems, subsystems, and equipment interfaces, including evaluation of failure modes

f. System engineering function/overview throughout the program.

g. Definition and control of system, subsystem, and component interfaces, including those with the Shuttle, TDRSS, GSTDN, POCC, and instruments.

h. Review all activities to assure contamination and environmental controls are implemented throughout the contract.

i. Perform analyses to ensure that the observatory design accommodates all required interfaces and design characteristics, including dynamic inputs from the instrument complement.

j. Reporting and control of system parameters, such as power budget, mass properties, telemetry and command handbook, mission timelines, etc.

3.3.1.1 Directed Systems Studies

The contractor, in addition to performing those studies required to accomplish the systems engineering tasks specified above, shall perform the following studies;

Attachment 2

STS Preliminary Minimum Assurance Requirements

REVISED

Discriminators Between Payload Classes

ap.	DISCIPLINE	CLASS A	CLASS B	CLASS C	CLASS D
.2	Flight Assurance Reviews				
	Number of reviews	Full cycle of six reviews	Full cycle of six reviews	Five reviews (System concept rev. optional)	Preliminary Design Rev. Pre-Integration Review primarily safety orient
.3	Performance Verification				
	a. Payload				
	1. Functional tests	All mission modes	All mission modes	Primary and safety related mission modes	Safety related mission
	2. End-to-end tests	All mission modes	All mission modes	Primary and safety related mission modes	Safety related mission
	3. Structural Loads	Analysis	Analysis	Analysis	Analysis for safety & STS restraints
	4. Vibroacoustic	Acoustic test	No requirement	No requirement	No requirement
	5. EMC	All tests	All tests	Less critical tests dropped	Safety related tests
	6. Vacuum, Thermal, & Humidity				
	a. Thermal-Vacuum	Test at highest practicable level of assembly	Test at highest practicable level of assembly	Thermal cycling may replace thermal-vacuum if no vacuum sensitivity exists	No requirement
	b. Thermal Balance	Test at highest practicable level of assembly	Test at highest practicable level of assembly	Test where significant performance uncertainties exist	No requirement
	c. Temperature, Humidity (Deorbit, descent & landing)	Analysis	Analysis	Analysis where significant performance uncertainties exist	No requirement
	d. Contamination	Analysis	Analysis	Analysis for constraints	Analysis for STS constra
	e. Leakage	Test	Test	Consider test	No requirement

Attachment 3

MISSION ASSURANCE AND PROPOSAL PREPARATION

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Virtually all system level RFP's contain a set of Mission Assurance requirements - some of them quite explicit, the rest implicit. The explicit requirements are embodied in reference documents such as MIL-Q-9858A, MIL-HDBK 217C, MIL-STD-1543, MIL-STD-721, MIL-STD-965, SAMSO Exhibit 73-2C, MIL-S-52779, MIL-STD-483, and MIL-STD-1540A. Most of you are familiar with these documents and know how to write a proposal responsive to these requirements and do not require guidance in these areas. The implicit requirements are much more difficult to recognize, and consequently are more difficult to address. The difficulty arises because a good system response requires the interaction between several disparate groups and the Mission Assurance activity (i.e., Systems Engineering, Program Management, and Cost and Pricing). This is further confounded by organizational structure and personalities.

In preparing the proposal response, it is important that the issue of "tailoring" be addressed. Tailoring can result in a cost-effective proposal, but extreme care should be taken to avoid the risk of being considered non-responsive. Therefore, the proposer should suggest that certain specification requirements be "tailored" to provide the equivalent mission assurance at lower cost or to provide increased mission assurance at equivalent cost.

If for reasons of a win strategy, even such tailoring is considered to be too risky, such suggestions can be offered in the form of alternate lower cost but mission-effective proposals. Such alternate proposals are usually allowed and encouraged by the RFP.

Mission Assurance is involved in all program phases, particularly in that of proposal preparation. This involvement and its shift in emphasis and skill requirements as in the program evolves are illustrated in Figure 1.

The degree of participation and the Mission Assurance organizational relationship must be clearly delineated by the contractor to provide the customer with the confidence that the proposed system will be effective and, if implemented, have a high probability of success (See Figure 2).

It is imperative that Mission Assurance become involved early in the proposal effort because the decisions affecting basic system architecture are made in the early stages of the effort. Once the architecture is established and detailed configurations and requirements are apportioned, cost estimating can begin. In this phase, Mission Assurance provides reliability models, mean-mission-duration calculations, life and parts degradation information, failure modes and effects analysis (FMEA), single point failure identification, and a preliminary hazards analysis. Systems Engineering uses all of these factors, among others, to develop and define the system. The Mission Assurance contributions are illustrated by Figure 3, Figure 4 (reliability model), Table 1 (typical failure rates), and Table 2 (P(s) calculations). The development of this information is an iterative process, requiring continual interface between Systems Engineering, Mission Assurance, and Management. It is beneficial during the System Definition Phase to co-locate these activities to encourage good communications.

Mission Assurance has developed several mathematical techniques to make system trades. These include Markov analysis (see Figure 5), optimum analysis using dynamic programming (see Figure 6), and Monte Carlo simulations (see Figure 7). All play a role in the Life Cycle Cost (LCC) process.

Mission Assurance is not, as generally supposed, divorced from the cost estimating process. In fact, Mission Assurance has a significant role to play in this area.

The trend in recent RFP's for operational systems is for the customer to specify an availability and the total system life, and the contractor to propose a total system, including the logistics, operations, number of satellites, spares, and design life. Estimates of mean-mission duration (MMD), probability of survival

(P_S), design life, and mean time to repair are made and used to develop total cost of ownership (TCO) using life-cycle cost models (LCCM). An imaginative approach in this area can have a dramatic impact on cost and in the probability of a win. Figures 8, 9, and 10, illustrate a typical satellite design as a function of parts, level, and design life, respectively.

An important parameter appearing more and more in current RFP's is system effectiveness, which relates reliability, availability, and performance. It can be expressed as E = P*R*A. The performance parameter is somewhat subjective; however, it may not necessarily be unity as some people may argue. For example, if a system may require several different sensors for different customers, it may not be possible to serve all of the users with a single platform. Comprises are required which result in a performance index which is less than unity (P 1). E can be calculated quickly with the nomograph shown in Figure 11.

Another important application of the Mission Assurance discipline is in defining and negotiating contract profit incentives. There is a trend requiring the contractor to accept negative incentives - meaning that the penalty for early mission failure is to dilute profit and to go into the basic cost. With FFP contract, this can be very painful.

Mission Assurance must be involved with the definition of failure, mission success, and partial success modes. Additionally, there is a desire on the part of mangement to reduce risk by insuring the incentive. The insurance companies require that the $P_{(S)}$ and MMD be calculated for all mission modes, and that the derivation for these failure rates be provided. The insurance companies understand and appreciate these estimates because of their actuarial expertise. They also want to see, and it is desirable to show, the reliability growth curves on proposed systems which are derivatives of existing systems. Good presentations in this area have big payoffs in both the contract incentivizing and on the insurance premium.

With the advent of the space shuttle (STS) era, a new dimension has been added to satellite system configuration development. For the first time it will be possible to retrieve failed satellites, or even repair them in orbit. Such goals are not as easily achieved as the media believes: nonetheless, retrievability is feasible. This results in Availability assessments for STS era satellites in which Mean Time to Replacement (MTTR) can truly include repair time rather than being limited to total replacement strategies of the Expendable Launch Vehicle era. Elaborate models have been constructed using mission assurance techniques (see Figures 12, 13, and 14). These show that implementing a retrievability capability pays only if the payload has a relatively low reliability and is very expensive. However, one cannot prejudge the outcome, and detailed models must be constructed and various cases run for each proposed system.

Another impact of the STS on systems design is the issue of replacement strategy. It now appears that scheduling for space on an early STS will be very difficult and costly. As such, the question of "launch on deman" versus storage "on orbit" must be addressed.

The expendable launch vehicle (ELV) provided the user with a great deal of flexibility. To maintain the satellite constellation in the STS era, one can schedule space on the STS on a regular basis and cancel if it is not required; however, this approach will be very costly. Storing in orbit will support the system availability; however, it subjects the satellite to degradation. Mission Assurance techniques must be utilized to provide estimates of MMD, life, and degradational factors for this on orbit storage option.

In the STS era, system safety is a major issue -- it is, in fact, the paramount consideration. Figure 15 shows a matrix of safety requirements. The proposal effort requires that a top-level hazards analysis be performed. as illustrated in Table 3.

The Mission Assurance activity is also deeply involved in the parts procurement program. Parts requirements are significant cost drivers, and must be viewed in the context of total system cost as illustrated in Figure 8, 9, 10, and 13.

A screening matrix such as the one shown in Figure 16 helps to avoid ambiguity, and is also useful for estimating costs.

Basically the message to space system contractors is simple: in addition to explicit requirement delineated in the RFP, there are the many implicit requirements which must be considered during evolution of the system baseline, and are an essential factor in a successful RFP response.

TABLE 1. PART FAILURE RATES FOR SPACE VEHICLE SYSTEM PRELIMINARY RELIABILITY ESTIMATE

ITEM		λ ($X10^{-9}$)* Failures/Hour
Integrated Circuits	Bipolar Digital (TTL&DTL)	
	1-20 gates	4.2
	21-50 gates	11.7
	51-100 gates	17.7
	Beam Lead, ECL, Bipolar & MOS Linear, Other MOS	
	1-20 gates	6.7
	21-50 gates	25.7
	51-100 gates	39.7
	Linear 32 transistors	7.7
	Linear 33-100 transistors	14.7
Transistors	Si NPN	4.1
	Si PNP	5.5
	FET	77.3
	Unijunction	51.4
Diodes	Si General-Purpose	2.6
	Zener & Avalanche	2.6
	Varactor, Step	240.9
Capacitors	Ceramic CKR	1.2
	Tantalum Solid CSR	1.2
	Tantalum Non-Solid CLR	5.4
	Paper/Plastic CHR etc.	1.1
	Glass CYR	1.3
	Variable Piston PC	16.9
	Filter (EMI Feedthrough)	5.0
	Mica CMR	0.9
Resistors	Composition RCR	1.0
	Film RNR	1.0
	Film RLR	1.6
	Wirewound Power RWR	1.2
	Wirewound Chassis Mount RER	1.4
	Variable Wirewound RTR	19.3
	Variable Non-Wirewound RJR	10.0
	Thermistor	20.0
Inductive	Power Transformer/Coils	30.9/15.3
	RF Transformer/Coils	33/17.4
Connectors Circular, Rack & Panel, PC		19.6
Relays Latching		40.1

* These failure rates were used for calculation of the Space Vehicle System Preliminary Reliability Estimate, and are in accordance with MIL-HDBK-217B.

TABLE 2. PRELIMINARY SYSTEM RELIABILITY ESTIMATE

EQUIPMENT	PROBABILITY OF SURVIVAL (P_S) FOR 1 YEAR ON-ORBIT
STRUCTURE & THERMAL CONTROL	0.9989
ATTITUDE CONTROL	0.9845
ELECTRICAL POWER & DISTRIBUTION	0.9875
COMMAND GROUP	0.9840
COMMUNICATIONS GROUP	0.9993
DATA PROCESSING GROUP	0.9750
TELEMETRY	0.9845
SPACE VEHICLE SYSTEM PRELIMINARY RELIABILITY ESTIMATE	0.9166

TABLE 3. TYPICAL PRELIMINARY HAZARD LIST[1] FOR SPACECRAFT/STS INTERFACE

Subsystem/ Function	Hazard Group (JSC 13830)	Hazard Event/Description	Applicable Safety Requirement (NHB 1700.7)
Electrical	Corrosion	Battery (Nickel-Hydrogen) leakage. Action of electrolyte if leak goes undetected for some time.	209-1, 208-4
	Electrical Shock	High voltage, associated with exposed connections or brought to exposed surface as result of a short.	213, 206
	Explosion	Battery, develops excessive internal pressure as a result of internal short or excessive temperature. Note: The battery normal operating pressure is in the 800 psi range, with case designed to a 3000 psi level. Development of excessive overpressure would only result from a series of catastrophic events possibly including case damage that would facilitate rupture at below design levels. Hazard reduction can be readily accomplished.	213, 209-1
	Fire	Battery release of hydrogen due to overcharge, electrical short, or damage to cell case or seal.	209-1, 209-3, 213
Environmental Control	Temperature Extremes	Heater malfunction that develops hot spot temperatures sufficient to ignite combustibles, or to develop system overpressures releasing combustible liquids or gasses.	213, 209-4
Materials	Contamination	Release of outgassing products or particulate matter during launch or landing.	209-4, 209-1
	Corrosion	Release of corrosive materials as a result of battery or propulsion (fuel) leaks (see applicable subsystem Hazard List) or release of corrosive outgassing or secondary material of corrosive nature as a result of temperature/time excursions.	209-1, 209-4
	Fire	Flammable material in contact with high temperature point source or in contact with fuel spillage.	209-1, 209-3

(1) The content of this table is compatible with JSC Form 542A (Feb. 78) which is the documentation format required by JSC 13830.

TABLE 3. TYPICAL PRELIMINARY HAZARD LIST FOR SPACECRAFT/STS INTERFACE (Continued)

Subsystem/ Function	Hazard Group (JSC 13830)	Hazard Event/Description	Applicable Safety Requirement (NHB 1700.7)
Mechanical	Collision	Failure of primary spacecraft structure during launch or landing loads.	208-1, 208-2, 208-3, 213
		Failure of cradle to maintain structural integrity during launch, landing, or deployment.	
		Inadvertent extension of solar arrays, antennas or booms prior to orbiter clearance minimums.	
Pressure Systems	Corrosion	Pressurized lines and fittings develop small leaks releasing hydrazine.	208-4, 208-5, 209-1
		Battery leaks develop as result of over-pressure or seal malfunction (see Electrical Subsystem).	
		Stress corrosion of metallic fittings, nuts, etc.	
	Explosion	Rupture of propellant lines, and tanks during launch, deployment, or emergency abort.	208-4, 208-5, 209-1, 209-3, 202-2b
		See Battery generated explosion potential under 'Electrical Subsystem Hazard List.'	
Propulsion	Collision	Inadvertent ignition of propulsion subsystem.	209-1
	Explosion	Rupture of propellant lines and tanks during abort, launch, and deployment (see 'Pressure' subsystem Hazard List.	202-2b
	Fire	Leakage of hydrazine from lines and fittings or release of battery generated hydrogen (see 'pressure' and 'electrical' subsystems).	209-1, 209-3, 213
Pyrotechnics	Collision	Inadvertent firing of an initiator causes propulsion ignition, deployment of extendable device, or release of spacecraft from cradle.	210-211 212-2
	Explosion	Same as above except that result is not translated into spacecraft motion.	
Radiation	Radiation	RF radiation escapes into orbiter bay during prelaunch, launch and pre-doors open phase due to inadvertent turn on of transmitters or seal leakage.	212-2
Structures	Collision	Failure of primary structure (spacecraft or cradle) causes impact with the orbiter bay walls or bay door as a result of severe deflection. Failure could occur during launch, abort, deployment, or landing (standard or emergency).	208-1, 208-2, 206-3

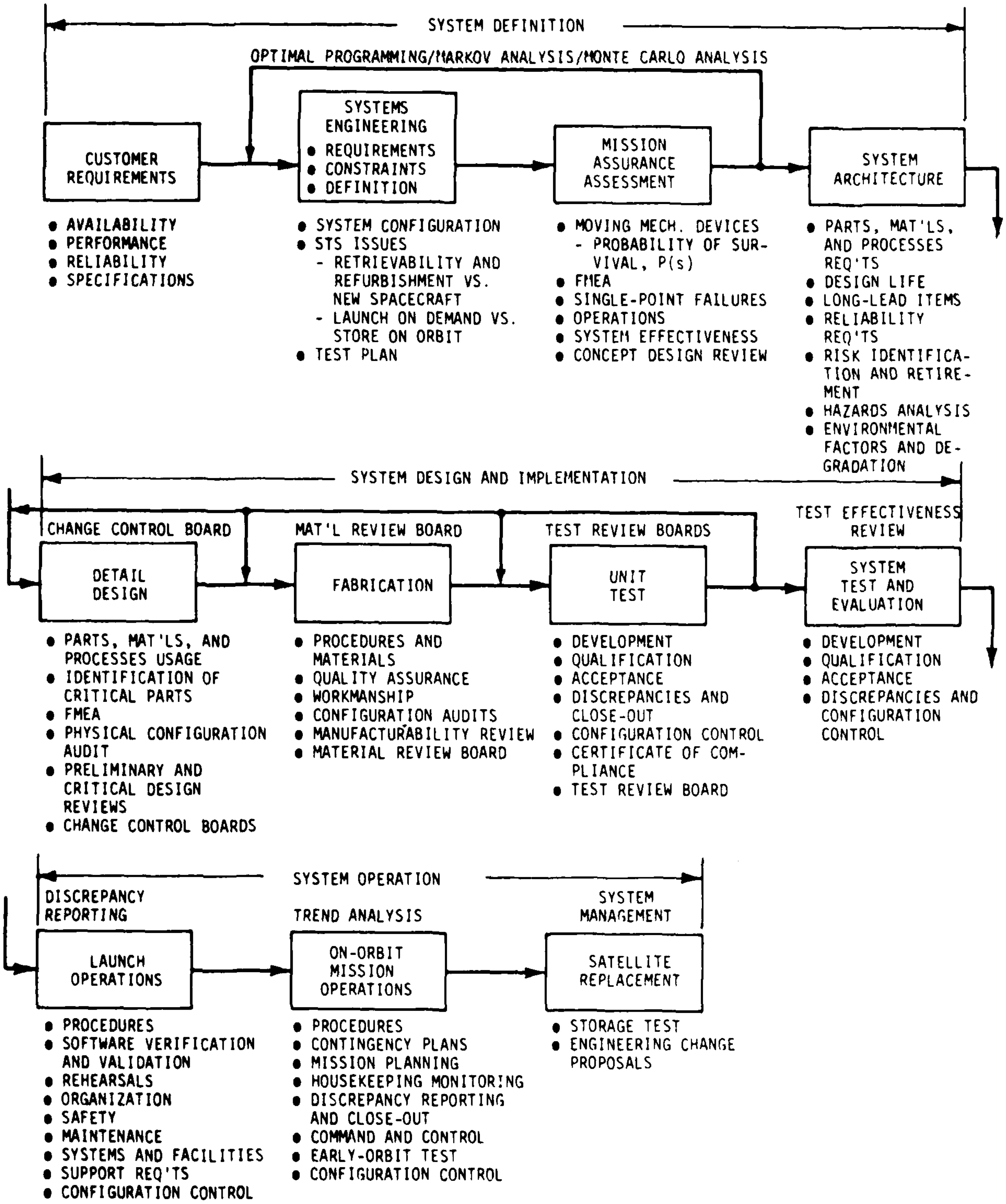


Figure 1. Mission Assurance Involvement in Space System Life Cycle

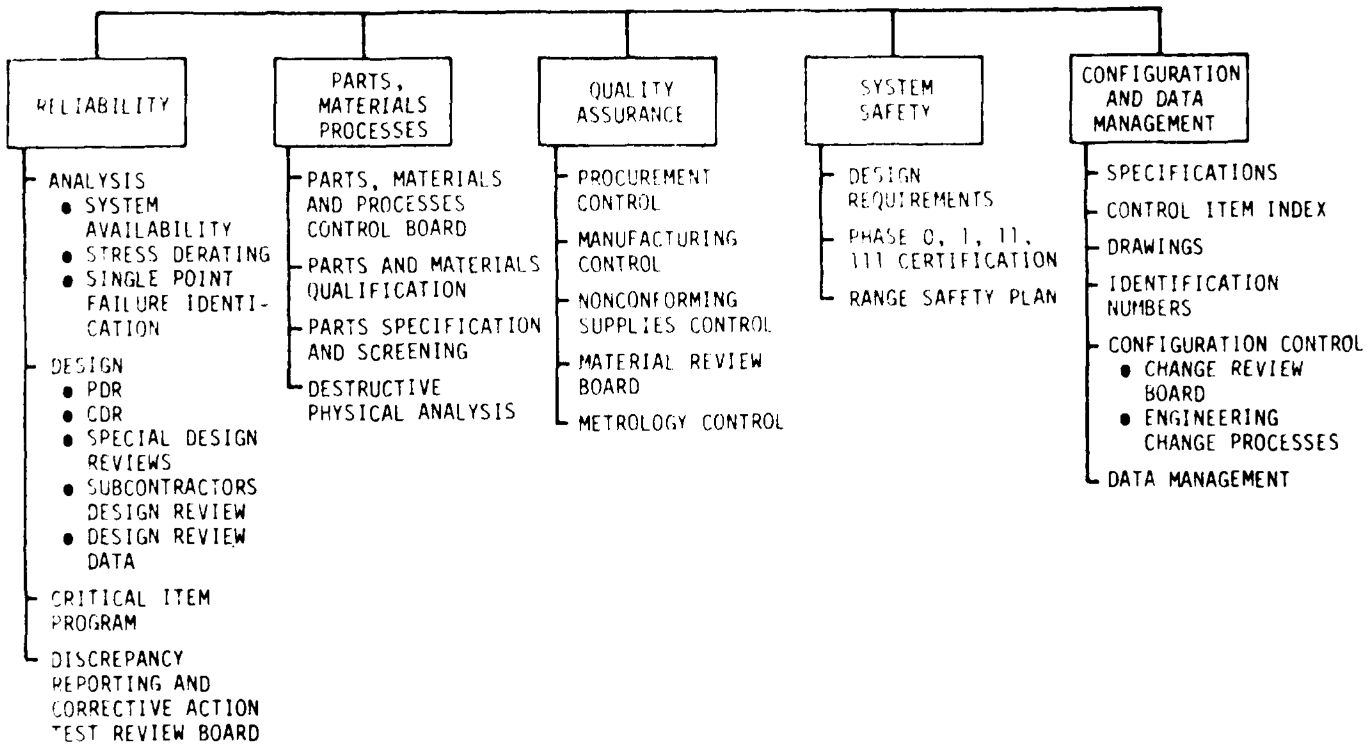
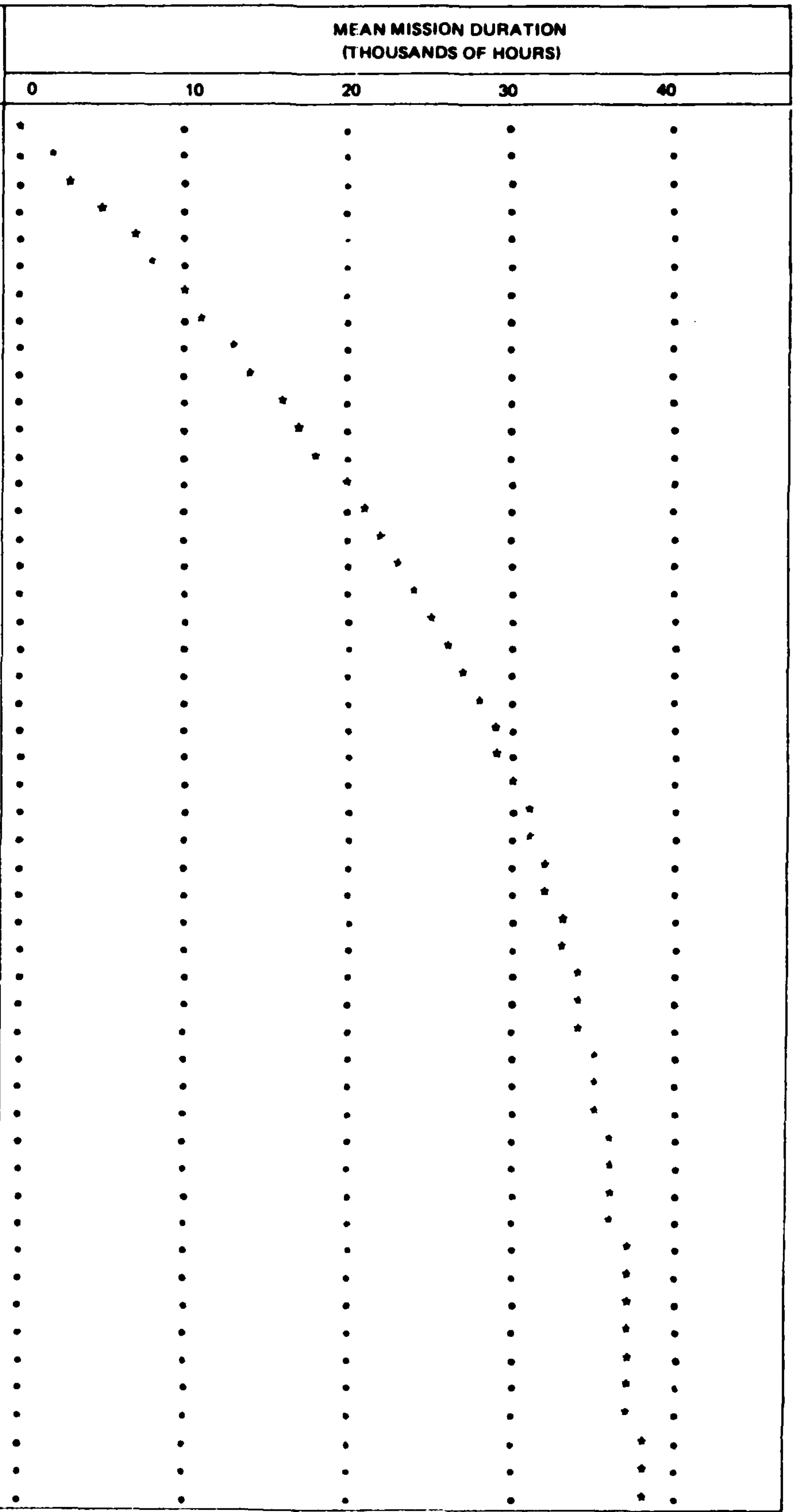


Figure 2. Mission Assurance Activities

INTERVAL	TIME OF TRUNCATION (HOURS)	MEAN MISSION DURATION (HOURS)
1	0.	0.
2	[illegible]	[illegible]
3	[illegible]	3417.
4	[illegible]	[illegible]
5	[illegible]	[illegible]
6	[illegible]	[illegible]
7	[illegible]	[illegible]
8	12271.	11461.
9	[illegible]	[illegible]
10	15777.	14422.
11	[illegible]	[illegible]
12	[illegible]	17166.
13	[illegible]	18461.
14	[illegible]	[illegible]
15	24542.	[illegible]
16	[illegible]	[illegible]
17	[illegible]	[illegible]
18	[illegible]	[illegible]
19	[illegible]	25113.
20	[illegible]	[illegible]
21	[illegible]	[illegible]
22	[illegible]	[illegible]
23	[illegible]	28523.
24	[illegible]	29257.
25	[illegible]	[illegible]
26	[illegible]	[illegible]
27	[illegible]	[illegible]
28	[illegible]	31770.
29	[illegible]	[illegible]
30	[illegible]	[illegible]
31	[illegible]	[illegible]
32	[illegible]	[illegible]
33	[illegible]	[illegible]
34	[illegible]	[illegible]
35	[illegible]	34797.
36	[illegible]	[illegible]
37	[illegible]	[illegible]
38	[illegible]	[illegible]
39	[illegible]	[illegible]
40	[illegible]	[illegible]
41	[illegible]	[illegible]
42	[illegible]	[illegible]
43	[illegible]	36744.
44	[illegible]	[illegible]
45	[illegible]	[illegible]
46	[illegible]	[illegible]
47	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]



NOTE: MEAN MISSION DURATION WAS CALCULATED IN ACCORDANCE WITH MIL-STD-1543(USAF).

Figure 3. Mean Mission Duration vs. Truncation time

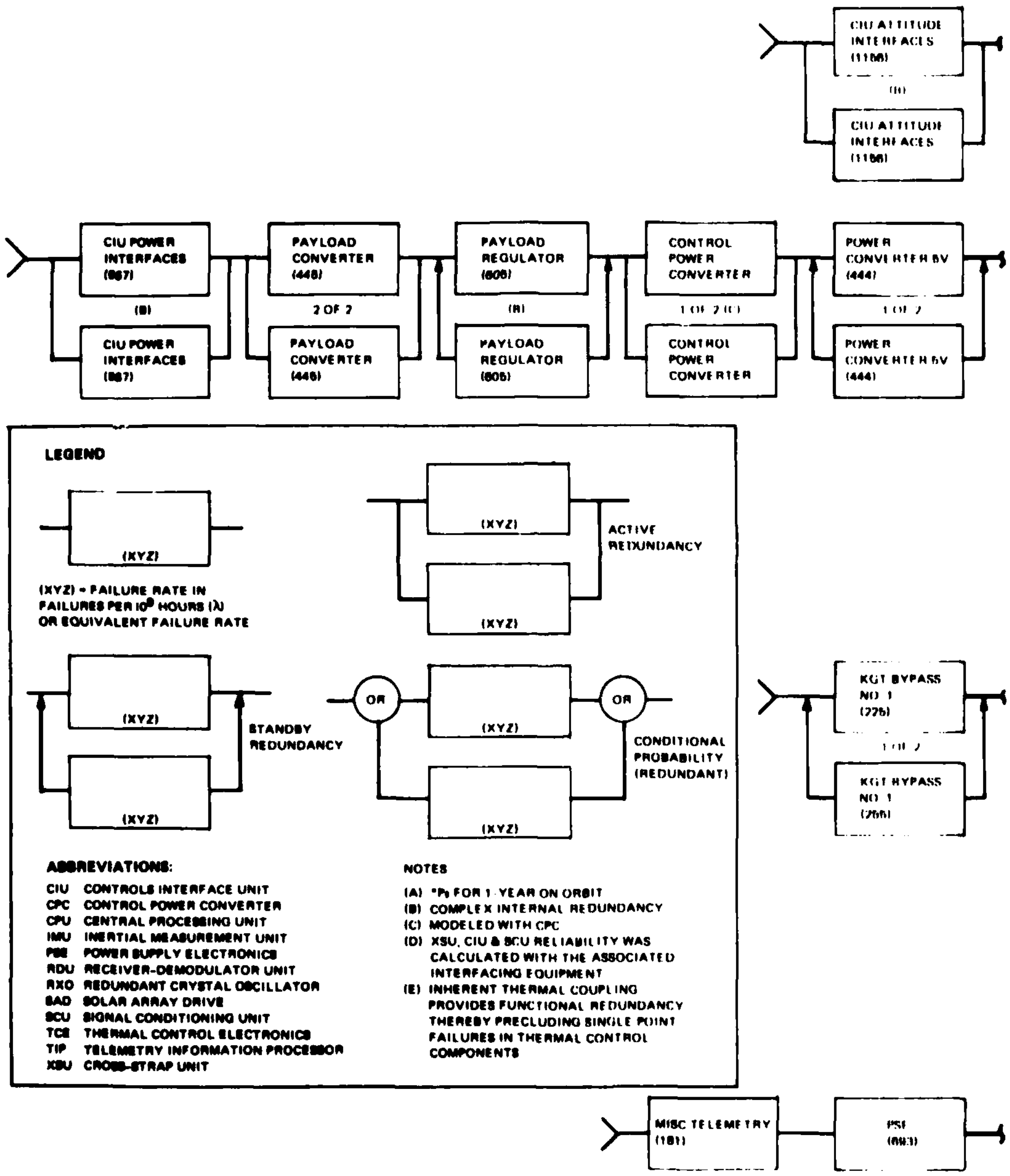


Figure 4. Satellite Reliability Model, On-Orbit Mission Phase

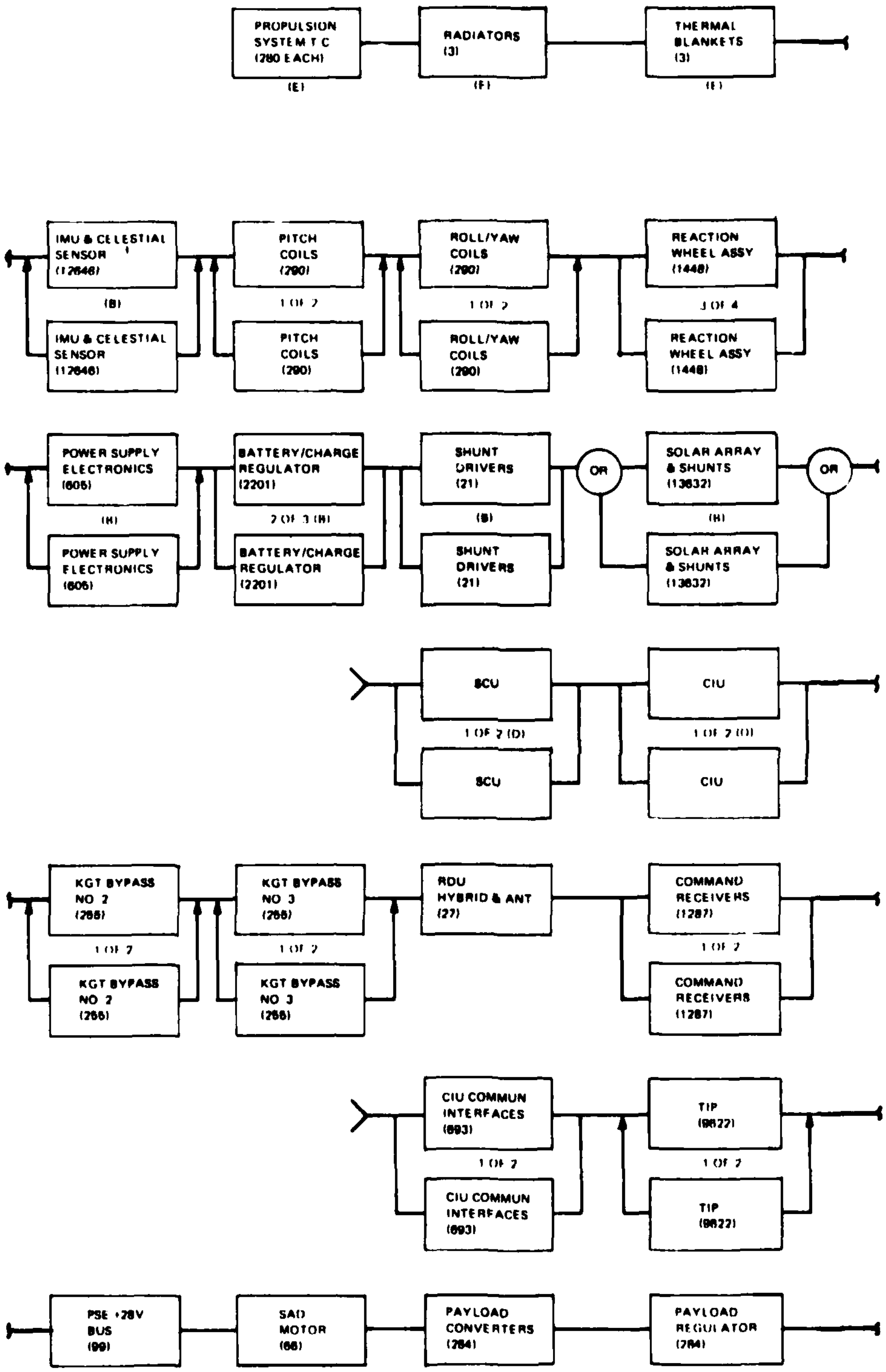


Figure 4. Satellite Reliability Model, On-Orbit Mission Phase (cont)

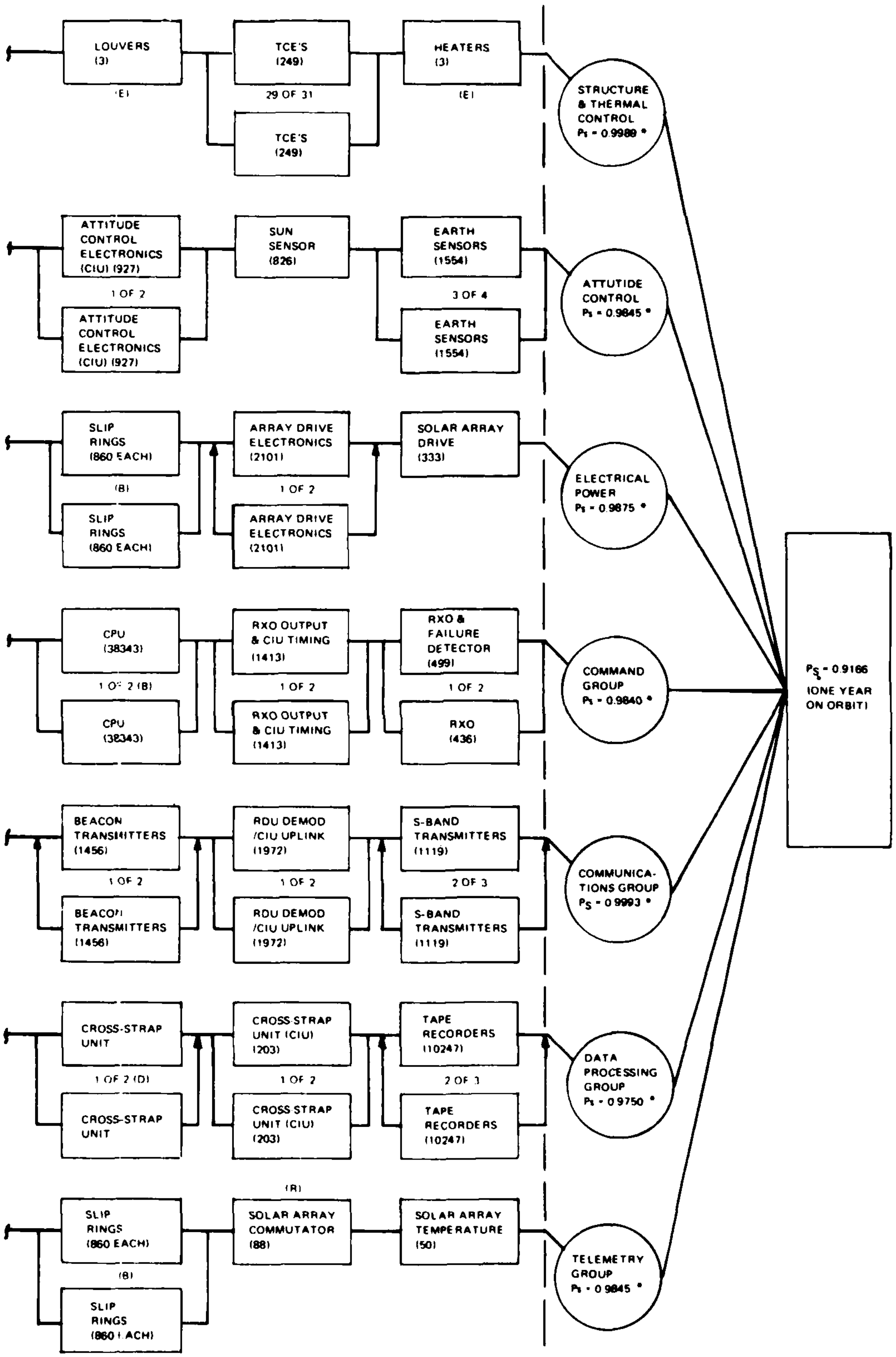


Figure 4. Satellite Reliability Model, On-Orbit Mission Phase (cont)

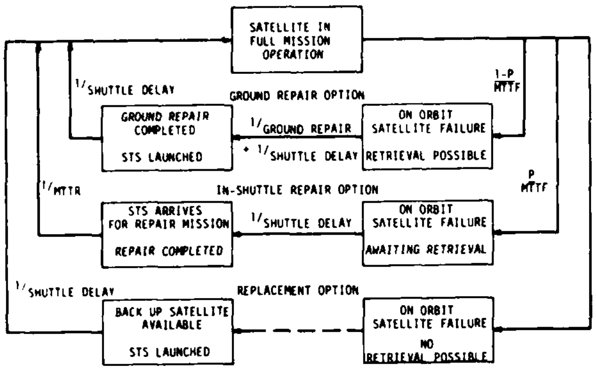


Figure 5. Satellite Repair Flow Diagram (Markov Analysis)

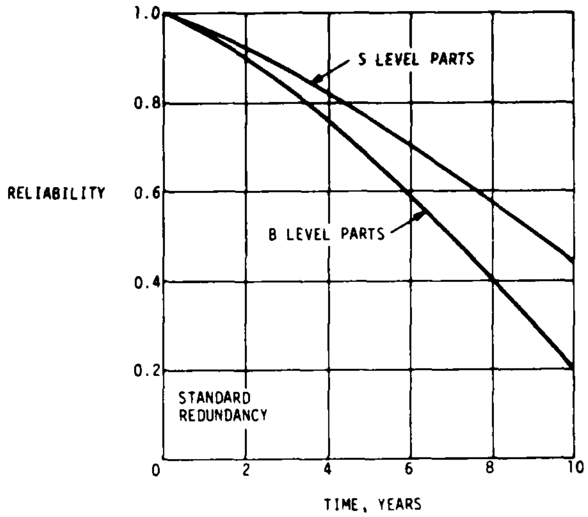
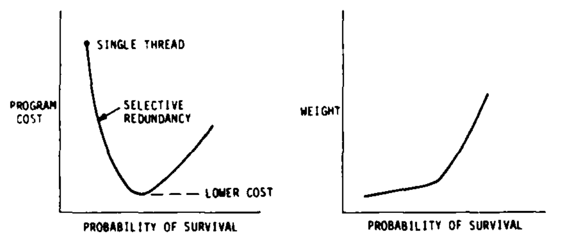


Figure 8. B and S Level Parts Reliability Predictions



- COST-OPTIMIZED ARCHITECTURE FOUND BY DYNAMIC PROGRAMMING--AN INTERACTIVE TECHNIQUE
- REDUNDANCY IS ADDED IN THE ORDER OF RELIABILITY IMPROVEMENT PER UNIT COST--LARGEST ADDED FIRST
- THE SAME TECHNIQUE CAN BE USED WITH WEIGHT AS THE CONSTRAINING PARAMETER INSTEAD OF COST

Figure 6. Optimized System Architecture

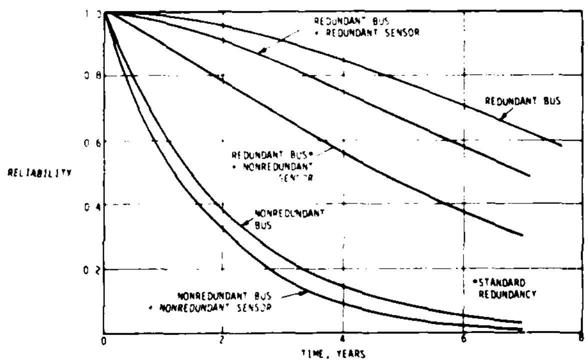


Figure 9. Reliability vs Time for Various Redundancy Levels

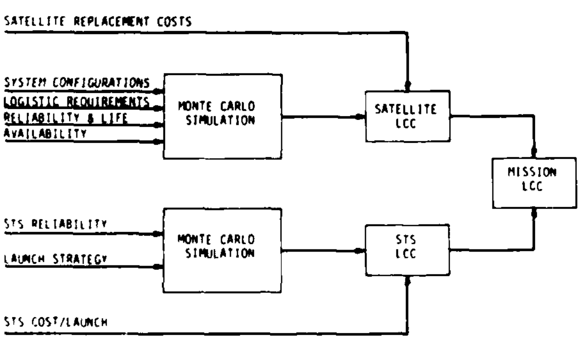


Figure 7 Life Cycle Cost System Design Optimization (Monte Carlo Analysis)

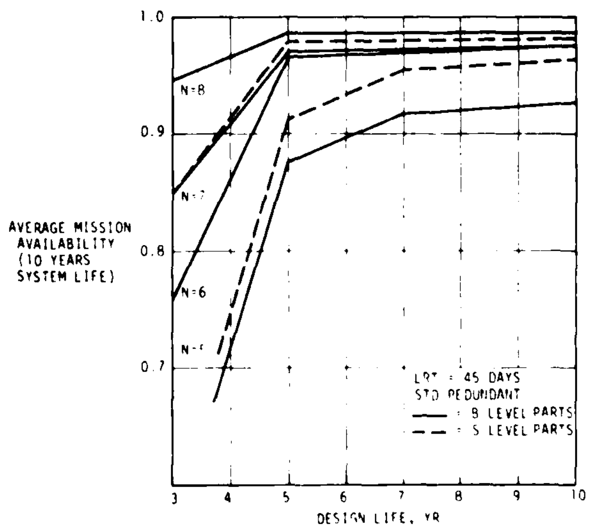


Figure 10. Availability vs Design Life for Redundant Satellite

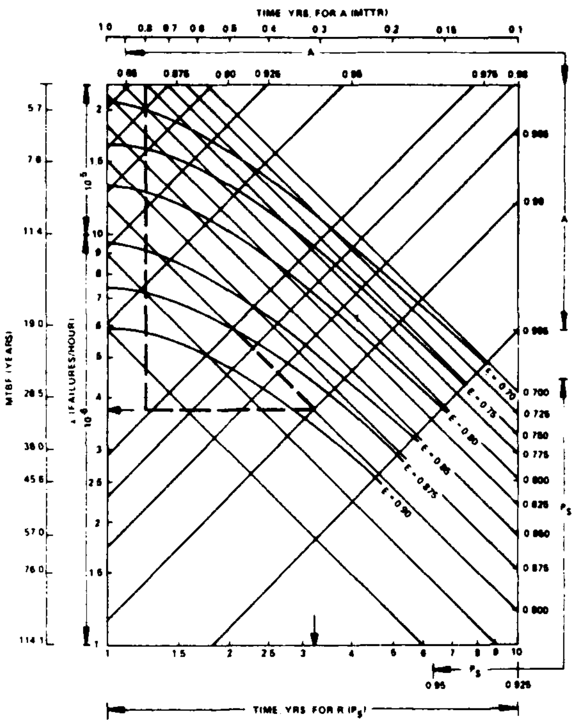


Figure 11 Reliability, Availability, and Effectiveness Model

- CASE 1: RECURRING AND NON-RECURRING COSTS ARE EQUAL

  AN = 50%, AR = 20%, E/C = 20%

  RV > 55% OF SPACECRAFT COST FOR 2 OF #

  > 90% OF SPACECRAFT COST FOR 1

- CASE 2: NON-RECURRING COST = 2 X UNIT COST

  RV > 80% OF THE SATELLITE COST OVER

  - 3 LAUNCHES ARE NECESSARY TO MAKE IT PAY.
  - FOR 2 OR LESS, IT DOESN'T PAY

- $RV > LC + \frac{E}{C} + \frac{1}{N-1}\,[AN + AR]$

WHERE:

RV = RECOVERED VALUE

LC = LAUNCH ORBIT

E/C = EXPENDABLES OR CONSUMMABLES USED IN RECOVERY

AN = ADDED NON-RECURRING COST TO IMPLEMENT RETRIEVABILITY IN THE SAT DESIGN

AR = COST ADDED TO MAKE SATELLITE RECOVERABLE (i.e., COST OF REPLACING WORN OUT ITEMS SUCH AS GYROS, AND MOVING MECHANICAL ASSEMBLIES)

N = NUMBER OF LAUNCHES RECOVERED N-1 IS USED BECAUSE THE LAST LAUNCH IS NOT RECOVERED

Figure 13. Repair in Orbit vs Retrievability vs Expendability

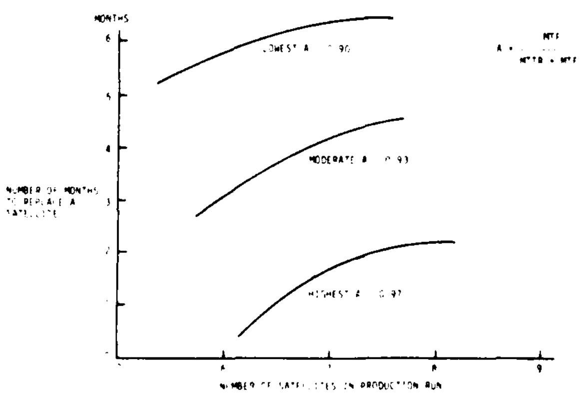


Figure 12. Launch Replacement Times to Achieve Mission Availabilities

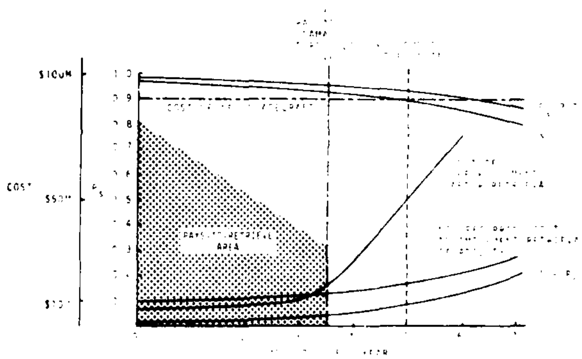


Figure 14 Retrievability Trade-Offs

- KMI 1710.1 KENNEDY SPACE CENTER SAFETY MANUAL - GROUND OPERATIONS
- K-STSM-14.1 KSC LAUNCH SITE ACCOMMODATIONS HANDBOOK FOR STS PAYLOADS
- NHB 1700 7 SAFETY POLICY AND REQUIREMENTS FOR PAYLOADS USING THE STS.
  - JSCICD 2-19000 SHUTTLE/CARGO STANDARD INTERFACES.
  - MIL-STD-1522 PRESSURIZED SYSTEMS - DESIGN STANDARDS.
    - NSS/HP-1740.1 PRESSURE VESSEL SAFETY STANDARD.
  - JSC 02681 NON-METALLIC MATERIALS LIST
    - JSC 09604 GFE NON-METALLIC MATERIALS LIST
  - JSC 07700 STS PAYLOAD ACCOMMODATIONS
    - JSC SP-R-0022 CONTROL OF OUTGASSING MATERIALS
      - JSC 07575 ACCEPTABLE MATERIALS LIST
      - JSC 08962 VOLATILE, CONDENSABLE MATERIALS LIST
  - JSC 11123 STS PAYLOAD SAFETY GUIDELINES HANDBOOK
  - MSFC-SPEC-522 DESIGN CRITERIA FOR CONTROLLING STRESS CORROSION CRACKING
  - JSC 13830 IMPLEMENTATION PROCEDURE FOR STS PAYLOADS SAFETY REQUIREMENTS
  - JSC 08060A STS PYROTECHNICS GUIDE
    - MIL-STD-1512 ELECTROEXPLOSIVES - DESIGN AND TEST
- NHB 5300.4 NASA HANDBOOK OF SYSTEM SAFETY FOR THE SPACE TRANSPORTATION SYSTEM
- AFETRM 127-1 AIR FORCE EASTERN TEST RANGE SAFETY MANUAL - LAUNCH OPERATIONS

Figure 15 NASA STS Safety Requirements Documents

No.	TEST AND INSPECTION REQUIREMENTS \ PART TYPE	DIODES: Rectifier	Switching	Tunnel	Voltage Ref	Voltage Reg	Varactor	Thyristor	TRANSISTORS: General	Power	FET	Unijunction	Microwave	µCKT: ICs	Hybrids
	100% SCREENING TESTS														
1	Supplier precap visual	●	●	●	●	●	●	●	●	●	●	●	●	●	●
2	Contractor precap visual													●	●
3	Parameter measurements	●	●	●	●	●	●	●	●	●	●	●	●	●	●
4	Centrifuge	●	●	●	●	●	●	●	●	●	●	●	●	●	●
5	Hermetic seal	●	●	●	●	●	●	●	●	●	●	●	●	●	●
6	Hi temp. reverse bias		●		●	●	●	●	●	●	●		●		
7	Hi temp. storage stab	●	●	●	●	●	●	●	●	●	●	●	●	●	●
8	Power burn in	●	●	●					●	●		●	●	●	●
9	Temp. cycle	●	●	●	●	●	●	●	●	●	●	●	●	●	●
10	Thermal shock														
11	Vibration														
12	Mechanical shock														
13	Power cond														
14	Voltage cond														
15	Overload														
16	PIND									●					●
17	Mech. performance														
18	Aging														
19	X-ray inspection									●			●	●	●
20	Run in														
21	Temp. run														
22	Resistance temp char														
23	External visual inspection	●	●	●	●	●	●	●	●	●	●	●	●	●	●
24															
	LOT SAMPLE SCREENING TESTS														
25	SEM												●	●	●
26	DPA	●	●	●	●	●	●	●	●	●	●	●	●	●	○
27	LAI	●	●	●	●	●	●	●	●	●	●	●	●	●	●
28	Radiation														
29															
	INCOMING INSPECTION TESTS														
30	DC leakage														
31	DC resistance														
32	Dielectric withstanding V														
33	Insulation resistance														
34	Capacitance														
35	Diss. Factor														
36	Pick up & drop out Voltage														
37	V_F & I_R				●	●									
38	BV, V_F & T_R	●	●												
39	BV, C & I_R						●								
40	I_{RBX}, I_{FBX}, V_{GT} & I_{GT}							●							
41	I_{CBO}, h_{FE}, $V_{CE(sat)}$								●	●			●		
42	BVCBO, BVEBO								●	●			●		
43	I_{GSS}, I_{DSS}, $I_{D(off)}$										●				
44	$V_{(BR)DSS}$										●				
45	I_{EB2O}, R_{BBO}, η											●			
46	Static parameters			●										●	●
47	Functional Tests													●	●
48	External visual inspection	●	●	●	●	●	●	●	●	●	●	●	●	●	●
49	Cleaning														
50	PIND	●							●	●	●	●		●	●

No.	TEST AND INSPECTION REQUIREMENTS \ PART TYPE	CAPACITORS: Ceramic	Glass	Mica	Paper plastic	Polycarb	Polystyrene	Mylar	EMC Filters	Tant foil wet slug	Tant solid	Variable
	100% SCREENING TESTS											
1	Supplier precap visual											
2	Contractor precap visual											
3	Parameter measurements	●	●	●	●	●	●	●	●	●	●	●
4	Centrifuge											
5	Hermetic seal									●		
6	Hi temp. reverse bias											
7	Hi temp. storage stab											
8	Power burn in											
9	Temp. cycle	●		●	●	●	●		●	●	●	●
10	Thermal shock											
11	Vibration											
12	Mechanical shock											
13	Power cond											
14	Voltage cond	●	●	●	●	●	●	●	●	●	●	
15	Overload											
16	PIND											
17	Mech. performance											
18	Aging											
19	X-ray inspection											
20	Run in											
21	Temp. run											
22	Resistance temp char											
23	External visual inspection	●	●	●	●	●	●	●	●	●	●	●
24												
	LOT SAMPLE SCREENING TESTS											
25	SEM											
26	DPA											
27	LAI	●	●	●	●	●	●	●	●	●	●	●
28	Radiation											
29												
	INCOMING INSPECTION TESTS											
30	DC leakage									●	●	
31	DC resistance											
32	Dielectric withstanding V											
33	Insulation resistance	●	●	●	●	●	●	○	●			●
34	Capacitance	●	●	●	●	●	●	●	●	●	●	●
35	Diss. Factor	●	●	●	●	●	●	●	●	●	●	●
36	Pick up & drop out Voltage											
37	V_F & I_R											
38	BV, V_F & T_R											
39	BV, C & I_R											
40	I_{RBX}, I_{FBX}, V_{GT} & I_{GT}											
41	I_{CBO}, h_{FE}, $V_{CE(sat)}$											
42	BVCBO, BVEBO											
43	I_{GSS}, I_{DSS}, $I_{D(off)}$											
44	$V_{(BR)DSS}$											
45	I_{EB2O}, R_{BBO}, η											
46	Static parameters											
47	Functional Tests											
48	External visual inspection	●	●	●	●	●	●	●	●	●	●	●
49	Cleaning											
50	PIND											

No.	TEST AND INSPECTION REQUIREMENTS \ PART TYPE	RESISTORS: Carbon Comp	Film Hi Stab	Film GP	Film Power	WW power	WW accurate	Variable	Thermistors	MISC: Filters potted	Inductors	Coils	Transformers	Connector potted	Connector	Relays	Fuse	Crystal
	100% SCREENING TESTS																	
1	Supplier precap visual															●		●
2	Contractor precap visual																	
3	Parameter measurements		●	●	●	●	●	●	●	●	●	●	●			●	●	●
4	Centrifuge																	
5	Hermetic seal															●		●
6	Hi temp. reverse bias																	
7	Hi temp. storage stab							●										
8	Power burn in																	
9	Temp. cycle		●	●	●	●	●	●	●	●	●	●	●				●	
10	Thermal shock																	●
11	Vibration															●		●
12	Mechanical shock																	
13	Power cond			●	●	●	●	●										
14	Voltage cond																	
15	Overload		●															
16	PIND															●		
17	Mech. performance							●										
18	Aging																	●
19	X-ray inspection																	
20	Run in															●		
21	Temp. run																	●
22	Resistance temp char								●									
23	External visual inspection		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
24																		
	LOT SAMPLE SCREENING TESTS																	
25	SEM																	
26	DPA																	
27	LAI	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
28	Radiation																	
29																		
	INCOMING INSPECTION TESTS																	
30	DC leakage																	
31	DC resistance	●	●	●	●	●	●	●	●	●	●	●	●			●		
32	Dielectric withstanding V																	
33	Insulation resistance													●				
34	Capacitance																	
35	Diss. Factor																	
36	Pick up & drop out Voltage															●		
37	V_F & I_R																	
38	BV, V_F & T_R																	
39	BV, C & I_R																	
40	I_{RBX}, I_{FBX}, V_{GT} & I_{GT}																	
41	I_{CBO}, h_{FE}, $V_{CE(sat)}$																	
42	BVCBO, BVEBO																	
43	I_{GSS}, I_{DSS}, $I_{D(off)}$																	
44	$V_{(BR)DSS}$																	
45	I_{EB2O}, R_{BBO}, η																	
46	Static parameters																	
47	Functional Tests															●		
48	External visual inspection	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
49	Cleaning													●	●			
50	PIND																	

Figure 16. Parts Screening and Inspection Matrix

CONTRACTOR PRE-SUBMITTAL PROPOSAL PREPARATION AND EVALUATION

H. Tom Morris

CONTRACTS/PROPOSAL MANAGEMENT
SPACE OPERATIONS & SATELLITE SYSTEMS DIV.
ROCKWELL INTERNATIONAL CORPORATION

Although the ultimate responsibility for evaluating proposals lies with the buyer, sellers must also evaluate their proposal before submittal to not only assure themselves that an achievable and reasonable approach can be developed but also that the best possible presentation is being made. Initially, an evaluation of the RFP requirements must be made to determine if seeking the business is in the best interests of the company and if the resources (technical, financial, facilities, etc.) are available should a contract be awarded. If the determination is made that the contract should be pursued, a proposal must be prepared keeping in mind the buyer's requirements and concerns.

I. BID DECISION

At the outset of the bid decision process a seller must decide if the type of contract and program risk are consistent. There are times when we will decide not to pursue a contract because of an unwillingness to accept the contract terms. Sometimes this conclusion is reached during the proposal preparation cycle. Much of our business is research and development work which does not lend itself to fixed price type contracting. Therefore, if we decide to seek the business we must find ways of minimizing our exposure. We have concluded that an important factor in successfully accomplishing this goal is to have a strong and effective Assurance Management organization. They are chartered with finding ways of increasing probability of mission success at minimum costs. As indicated later, this organization is an important part of the red team.

It they conclude that necessary program deciplines (e.g. high reliability parts) cannot be accomplished within the allocated resources, a decision must be made as to the available tradeoffs and how the ultimate approach selected will meet the buyer's objectives.

II. EVALUATION PROCESS

Prior to final approval and submittal of the proposal, we usually have a "red team" evaluate the proposal. This team consists of individuals who become familiar with the requirements specified in the RFP and SOW, but are not involved in the actual proposal preparation, and are knowledgeable of the capabilities of the company. It is their job to not only assure that from the company's standpoint the proposal makes sense, but that the requirement established in the RFP/SOW is being fully met in the most desirable manner. To do this requires a detailed review by several individuals. Assignments are made to review technical approaches to assure that they are not only feasible, but provide for low risk programs. When non-recoverable satellites are involved, assurance that mission objectives will be met is of primary concern. It, therefore, becomes extremely important to be able to demonstrate that not only the design concept meets mission requirements but that a management system exists to provide the diciplines needed to produce a reliable product.

In reviewing the proposal presentation and evaluating whether it will "sell", the red team looks for several things that will make the proposal more effective.
These are:

1) Does your story come across early and spark the readers interest?
2) Does the message emphasize the buyers gain in what is being proposed and the advantages of the proposed approach?

II. EVALUATION PROCESS (continued)

3) Is the presentation specific in its approach?

4) Is the presentation written in a positive style?

5) Is the proposal written in a manner that the buyer will understand all the details of the proposed, technique and the terminology used?

6) Is the presentation brief and to the point?

7) Is related experience clearly set forth?

To assist our red teams a Proposal Checklist is utilized similar to the one set forth in Section III. Each red team chairman will tailor it to meet his own needs.

Normally, the red team consists of key members of the technical and administrative staffs and may, if appropriate, include major subcontractors. One of the members represents Assurance Management and is responsible for evaluating the technical design aspects that deal with mission assurance, such as reliability, system safety, and configuration control as well as the production aspects including manufacturing processes, parts control, and inspection procedures. Each member reviews his assigned area and reports to the team Chairman who will make recommendations to the proposal manager. Any agreed to changes and proposal improvements are incorporated into the proposal prior to initiating the formal review process. A key ingredient to this evaluation is a "risk assessment." This involves taking the RFP/SOW requirements and evaluating the probability of satisfying these requirements within the cost, schedule and terms of the contemplated contract. If a program is deemed to be a "high risk" venture, additional management reviews are required to obtain approval to propose. One of the techniques utilized by our "red teams" is to take the major elements of the proposal and rank them in order of importance which is felt to be consistent with the way the buyer will rank them. This is done not only with the technical aspects but also cost and schedule. A determination is made as to whether the proper emphasis has been placed in the manner the buyer's priorities have been established. Hopefully, utilizing the RFP and answers to submitted questions, a proper alignment can be made. If it turns out an area has been over (or under) emphasized, adjustment must be made.

The problem with this type of evaluation process is that it takes time, and time is normally a very rare commodity. To turn a proposal around in 45-60 days when there are subcontractors involved is difficult at best. By the time the technical approach is established and priced, there is little or no time left for a comprehensive evaluation. Therefore, it is necessary to get a jump on the RFP/SOW. Very often a proposal is completed or near completion before RFP is issued. The buyer's needs and priorities are determined through marketing efforts and hopefully not too many changes need be made to the technical approach already established.

This early start is essential, as a proposal that does not get the necessary review before it is submitted will be successful only by sheer luck, and a series of poorly organized non-responsive proposals may damage the reputation of the company.

The tendency today is to try and contract on a fixed price basis, either firm fixed price or some type of incentive arrangement. One of the decisions a seller must make during the evaluation process is whether the SOW and type of contract are compatible and whether sufficient costs and time have been provided for. Very often ways have to be sought to minimize risk while reducing (or at least maintaining) the estimated costs. This can lead

II. EVALUATION PROCESS (continued)

to alternate proposals, which sellers normally do not desire preparing.

III. PROPOSAL CHECKLIST

A. Technical Approach

This section should provide an analysis of the problem, a discussion of the operational environment and an accurate and clear technical description of the proposed system and/or hardware, including drawings or sketches of the proposed configuration. The following should be considered:

1. Is there a clear concise statement of the technical requirements which the proposal fulfills?

2. Is the technical problem as seen by the customer clearly delineated? - not simply "parroted" from RFP? Is the proposal responsive to the technical requirements?

3. Does the proposal convincingly show a depth of understanding of the problem?

4. Is there a brief dicussion of alternate solutions which were explored and rejected and the reason for their rejections?

5. Is there a discussion of technical approaches to be explored and why the company's approach may be expected to yield the desired results?

6. Have unrealistic and unreasonable performance requirements been identified and alternatives suggested?

7. Have the more difficult areas been identified and detail provided showing how performance requirements never before achieved will be met?

8. Have excessive costs or time delays required to meet certain specific requirements been clearly pointed out?

9. Is there a statement of major technical problems which must be solved with an indication as to the amount of effort budgeted to each?

10. Is the relation of proposed solution to the broader over-all system with which it will operate shown?

11. Is there a description of the hardware which the contractor expects to furnish?

12. Does the proposal state where the company intends to deviate from standard military specifications? How much? Why?

13. Does the proposal show that proper consideration has been given in the operational concept to serviceability and ease of maintenance?

14. Is an estimate furnished of maintenance procedures and schedule showing to what extent special test or support equipment will be required?

15. If new components must be developed, does the proposal explain why existing ones cannot be used?

16. Are unique or unusual components described and justified?

17. Is an estimate provided as to the likelihood of the program resulting in usable hardware?

III. PROPOSAL CHECKLIST (continued)

A. Technical Approach (continued)

18. Is convincing technical substantiation of the design proposed?

19. Does the approach avoid over-engineering and over-sophistication?

20. Is a manhour estimate (not costs) included in the technical portion of the proposal?

B. Technical Ability

This Section should clearly demonstrate the overall technical competence of the company to successfully complete the specific project involved.

1. Does the proposal provide convincing assurance of specific technical competence for this project?

2. Does the proposal give specific examples of similar projects successfully completed?

3. Is information provided as to the relation of the proposed hardware to existing or previous programs which the company has done for other customers, indicating the customer, project, and funds already spent?

4. Do the biographies relate specific experience of personnel to the specific needs of this project? Has extraneous biographical information been eliminated?

5. Is the availability of specific people clearly detailed - - in terms of manhours for both full-time and part-time people?

6. Since the customer knows that the same personnel are used for different proposals, does the proposal show a depth of qualified personnel?

7. Are areas of technical weakness identified and does the proposal show how this will be compensated for - for example by subcontracting or the use of consultants?

8. Does the proposal clearly indicate that there is adequate technical space and facilities, both general and special to perform work efficiently and on schedule?

9. Does the proposal outline the availability of the facilities, Government-owned, owned, or leased, necessary for the specific project, for research, development, production and testing?

10. Are special technical facilities (such as dust-free laboratories, temperature controlled rooms, data processing equipment, special laboratory equipment) required by the project clearly spelled out?

11. Is it clearly indicated that all required facilities will be available when required for this project?

12. Where Government-furnished equipment is required, are these needs clearly justified?

13. Is a facility plan provided showing layout, tests, dollar value and square footage?

14. Where tie-ins with subcontractors are proposed, is specific evidence given of the subs' commitment to make technical people and facilities available when required?

C. Delivery Requirements and Scheduling

Delivery is most important. The proposal must not only state that the delivery schedule will be met, it must show how it will be met.

III. PROPOSAL CHECKLIST (continued)

C. Delivery Requirements and Scheduling (continued)

1. Does the proposa. provide convincing assurance that the customer's delivery dates will be met or bettered?
2. Is sufficient detail regarding master scheduling, programming, follow-up, and other like functions given to reinforce the foregoing assurance?
3. Where subcontractors and major suppliers are involved, are sufficient safeguards built into proposed scheduling system to insure sub-schedule compliance with master program?

D. Project Direction and Management

The proposal should show the company's method of management. It should elaborate on organization personnel manpower controls. It must demonstrate that the company has an understanding of the external organization relations with the Government or Prime Contractor and with subcontractors necessary to the accomplishment of the project. It must outline the overall management concepts employed by the company and the specific type of management that will be provided for the proposal project.

1. Does the proposal clearly demonstrate an understanding of the customer's concern with the management of this project?
2. Are details provided on corporate experience, facilities and personnel?
3. Does the proposal demonstrate that top-level management will continue a high level of interest and assume responsibility for successful accomplishment of the program?
4. Is evidence given of management's understanding of how the specific project fits into the customer's over-all needs?
5. Are details provided on management objectives, policies, participation, and reliability concepts?
6. Does the proposal show how the interest of the company in this specific project ties in with the company's long-range plans as well as with past experience?
7. Does the proposal outline the type of management to be provided for the project.
8. Is information furnished as to the type frequency, and effectiveness of management controls and methods for corrective action?
9. Do the manpower buildup charts clearly explain the methods of manpower acquisition, particularly skilled manpower requirements?
10. Is a total manpower plan and individual plans for engineering, manufacturing and quality control furnished?
11. Is information furnished showing how the present project will phase in with current and future business?
12. Is a Make-or-Buy Program provided?
13. Is evidence given of the complete support of the subs' management for an arrangement wherein the company would be the system manager?

E. Quality Assurance, Quality Control and Reliability

The term "Quality Assurance" covers all the actions necessary to adequately determine that product requirements are met. "Quality Control" is the system and management function by which the Contractor ascertains and controls the quality of supplies or services. "Reliability" is the ability of item to function without failure. The proposal should carefully delineate the company's programs in these areas.

III. PROPOSAL CHECKLIST (continued)

E. Quality Assurance, Quality Control and Reliability (continued)

1. Does the proposal describe the company's quality control plan?

2. Is it clear that the customer's quality control requirements will be achieved by the company's quality control system?

3. Are deviations from customer requirements satisfactorily explained?

4. Does the proposal show that customer reliability requirements can be achieved by the company's concept and approach, including a specific program for meeting or surpassing these requirements?

5. Is it clearly shown how the reliability organization and project responsibility fit into the proposed program?

6. Are reliability monitoring points clearly delineated so that customer surveillance may be effectively exercised?

7. Does the proposal show an understanding of reliability prediction techniques and spell out in detail how predicted goals will be met?

8. Is creative ingenuity reflected in the proposal by pointing out reliability approaches to particular development Phases?

F. Manufacturing

The proposal should show the company's competence to manufacture the item. Some information in this field is important even in proposals for research and development which may not involve any quantity production, since the buyer must usually give consideration to an plan for future production quantities.

1. Does the proposal describe the company's manufacturing organization responsibilities?

2. Does the proposal expain the system and procedures used for schedule planning and operational controls?

3. Does the proposal provide convincing assurance of specific manufacturing competence in terms of this project?

4. Does the proposal clearly indicate that the company has adequate manufacturing space and facilities?

5. Does the proposal show evidence of an effective manufacturing control system?

6. Does the proposal state that all required facilities are available?

7. Does the proposal provide evidence that the company utilizes the most advanced methods in its manufacturing and manufacturing support areas?

In addition to the above sections, areas such as price, field support, proposal format, would be covered in the checklist.

IV. POST AWARD ANALYSIS

The evaluation process need not stop once the award is made. In addition to any buyer initiated de-briefing, it may be advisable to conduct an in-house evaluation of the factors that contribute to a loss, or even a win. This evaluation can be very beneficial in future proposal activities. Understanding "why" the buyer reacted to your proposal the way he did can help in making the next proposal more responsive to needs of the buyer. It is equally important to know where you did well in order that you can do it that way again. This evaluation can be used to determine the buyer's attitude toward your firm in order that strengths can be exploited and weaknesses corrected.

V. SUMMARY

Very rarely, if ever, does a company win everything they bid on. So the key thing is to continually improve your win/loss ratio. One of the

V. SUMMARY (continued)

most important ways of doing this is to understand your customer and prepare your bids so they are meaningful to him. Internal evaluations of your proposals to insure that all objectives are being met is mandatory to achieving a goal of high awards. Having the technical capability is not enough if you can't express this to your customer in a way he is satisfied you can do the best job for him.

Many hours and dollars can be spent developing a proposal that never get your message across and thus is not selected. Being geared to start quickly and have enough time to not only properly evaluate your product but also make improvements will help you win more awards and perform at a profit. Winning is great, but not if the risks are not consistent with the price, schedule, etc. and you therefore lose money.

Don't be afraid to ask for a de-briefing. Most buyers are very willing to give you some insight into how your proposal was evaluated. This information will be very helpful the next time around. Keep records of what you thought were key concerns of the buyer and whether you were right or not.

THE PROPOSAL GAME
DR SAM SILVERBERG
HUGHES AIRCRAFT CO

PREMISE

IT'S NOT HOW GOOD A CONTRACTOR IS, BUT RATHER HOW GOOD THE GOVERNMENT EVALUATORS PERCEIVE HIM TO BE THAT IS OF CONSEQUENCE DURING PROPOSAL EVALUATIONS.

CUSTOMARY GOVERNMENT/ CUSTOMER INTERCHANGES

- O BIDDER'S CONFERENCE
- O RESPONSE TO BIDDERS' CONFERENCE
- O DRAFT RFP/COMMENTS
- O TECHNICAL PRESENTATIONS BY CONTRACTORS
- O "CASUAL" MEETINGS WITH CONTRACTOR MARKETING REPRESENTATIVES
- O COMMENTS ON FINAL RFP
- O PROPOSAL (WRITTEN/ORALS)

PROPOSAL WRITING

- O PRESENT THE OFFERING IN THE BEST POSSIBLE LIGHT
- O AVOID MENTION OF YOUR WEAKNESSES
- O ALLUDE TO COMPETITOR'S WEAKNESSES
- O CONTINUALLY INTERWEAVE THOSE THEMES KNOWN TO BE IMPORTANT TO THE CUSTOMER

PHASE II THEME DRILL

1. WE HAVE A UNIQUE SOLUTION TO YOUR UNIQUE REQUIREMENTS.
2. DEDICATED TOTAL ORGANIZATION - NEW FOR THIS JOB.
3. UNIQUE ORGANIZATIONAL STRUCTURE - "CRADLE-TO-GRAVE-" MANAGEMENT CONTINUITY.
4. ADVANCED UNDERSTANDING OF JOB DUE TO SIGNIFICANT PRIOR INVESTMENTS.
5. EXISTING PROGRAM X REFINES OUR TECHNOLOGICAL UNDERSTANDING FOR PROGRAM Y.
6. TEAMED WITH ESTABLISHED SISTER COMMERCIAL DIVISION TO OFFER CREDIBLE "IN-HOUSE" LOW COST OF BOTH.
7. UTILIZING INTEGRAL ELECTRONICS IN A PREVIOUSLY ALL-MECHANICAL DEVICE SIMPLIFIED CONSTRUCTION WHILE YIELDING SUPERIOR PERFORMANCE.
8. LOW RISK DEVISED FROM OPERATING BREADBOARDS.
9. KEY PAYLOAD ELEMENT HAS FLOWN SUCCESSFULLY THEREBY REDUCING RISK.
10. PROVEN PERFORMANCE - OUR PRODUCTS HAVE ALREADY FLOWN TO THE MOON AND RETURNED AND ARE NOW FLYING BY JUPITER.
11. OUR TECHNICAL EXPERTISE WILL PROVIDE SUPERIOR DESIGN AND PERFORMANCE AND WE ARE TEAMING WITH OUR SISTER CORPORATE DIVISION WITH 115 YEARS OF PROVEN MANUFACTURING EXPERIENCE TO INSURE DELIVERY OF THE PRODUCTION PRODUCT ON SCHEDULE AND AT LOWEST POSSIBLE COST.
12. INDEPENDENT ACCOUNTING SEGMENT FORMED TO TAILOR OVERHEAD AND G&A TO UNIQUE ASPECTS OF BUSINESS.
13. OUR COMPANY IS UNIQUELY SUITED TO BUILD THE FULL MISSION SIMULATOR BECAUSE WE BUILT THE AIRPLANE.
14. WE HAVE MAXIMIZED PERFORMANCE WHILE ACHIEVING A BALANCE BETWEEN LOW INITIAL ACQUISITION AND LIFE CYCLE COSTS.
15. OUR EXHAUSTIVE TRADE STUDIES INSURE LOW LIFE CYCLE COSTS WITH EXISTING TECHNOLOGY ITEMS MATCHING ALL REQUIREMENTS.
16. OUR AIRPLANE OFFERS MAX OPERATIONAL UTILITY WITH A MINIMUM CREW COMPLEMENT-LOWER LCC.
17. STATE OF THE ART TECHNOLOGY INSURES UTILITY AND GROWTH WELL INTO 1990 TIMEFRAME.
18. THE AVIONICS SUITE IS DESIGNED FOR EASE OF EXPANSION AND RE-PROGRAMMING *WITH MINIMUM* AIRCRAFT MODS.
19. OUR AIRCRAFT PERFORMANCE HAS BEEN DEMONSTRATED SUPERIOR TO ALL OFFERORS.
20. WE USE OUR OWN MANUFACTURED FIELD-PROVEN PARTS TO SAVE DEVELOPMENT COSTS THROUGH STANDARDIZATION.
21. WE HAVE BEEN USING CORPORATE FUNDS TO DEVELOP THIS TECHNOLOGY FOR YEARS, AND ALL THIS EXPERIENCE IS AVAILABLE AT NO COST.
22. WE HAVE BEEN MANUFACTURING MORE THAN 8000 DIFFERENT PRODUCTS FOR MORE THAN 50 YEARS, MANY OF WHICH REQUIRE SIMILAR TECHNIQUES.
23. WE ARE AMONG THE PIONEERS IN CRYOGENICS RESEARCH AND DEVELOPMENT, AND UNDERSTAND THE REQUIREMENTS COMPLETELY.
24. WE HAVE BUILT AND TESTED A DEMONSTRATION UNIT WITH CORPORATE FUNDING AND ARE COMPLETELY COMMITTED TO THE TECHNOLOGY.
25. THE PROPOSED SYSTEM IS SIMILAR TO THOSE ALREADY BEING MANUFACTURED AT ONE OF OUR DIVISIONS.
26. WE HAVE THE REQUIRED PERSONNEL IN PLACE, AVAILABLE, AND UP TO SPEED.
27. WE ARE A RECOGNIZED LEADER IN THIS FIELD AS DEMONSTRATED BY HUNDREDS OF

RELATED CONTRACTS, WORLDWIDE.

28. WE HAVE AN OUTSTANDING RECORD OF MANAGEMENT ON SIMILAR PROGRAMS IN TERMS OF TECHNOLOGY AND DOLLAR VALUE.

29. WE HAVE DONE EXTENSIVE INTERNAL STUDIES AND UNDERSTAND THE CUSTOMER NEEDS.

30. OUR COMPANY HAS PROVEN RECORD OF ON-TIME DELIVERIES, WITHIN COST.

31. OUR COMPANY HAS PROVEN RECORD OF 99% RELIABILITY IN MICROWAVE RELAYS.

32. OUR COMPANY DEVELOPED THE PROTOTYPE.

33. PERSONNEL WHO DEVELOPED AND DEMONSTRATED HIGH PERFORMANCE TECHNOLOGY AVAILABLE FOR THIS PROGRAM.

34. WITH OUR TECHNICAL AND MANAGEMENT ORGANIZATION IN-PLACE, NO PROGRAM TIME, OR DOLLAR RESOURCES WILL BE WASTED RECRUITING AND TRAINING AN ORGANIZATION.

35. OUR TECHNICAL PERFORMANCE IS DOCUMENTED IN YOR UR RECORDS WHICH SHOW NO FAILURES IN THE CAST (X) AN-YY AND (Y) APS-RR UNITS.

36. ALL PRODUCTION EQUIPMENT REQUIRED TO INITIATE, BUILD TO AND MAINTAIN YOUR REQUIRED DELIVERY RATE IS IN PLACE AND READY.

37. SINCE YOUR MANAGEMENT SYSTEM INDICATOR SYSTEM WAS INITIATED ALL MSI'S HAVE BEEN "GREEN".

38. THE OPERATING PROTOTYPE OF OUR PROPOSED DESIGN HAS ALREADY SEEN (X) BENCH HOURS AND (Y) ENVIRONMENTAL TEST HOURS WITHOUT A FAILURE.

39. IN OVER A DECADE OF DESIGNING, DEVELOPING AND PRODUCING X'S, EVERY DELIVERY HAS BEEN ON OR AHEAD OF THE ORIGINAL CONTRACT SCHEDULE.

40. THE PROPOSED BASELINE DESIGN HAS BEEN ITERATED THREE TIMES TO IDENTIFY ALL COST DRIVERS AND THEIR IMPACTS.

41. IN THIS DESIGN PROCUREMENT - OUR DESIGN IS ALREADY COMPLETED.

42. OUR TEST FACILITIES SEEM TO HAVE BEEN DESIGNED WITH YOUR HARDWARE IN MIND.

43. OUR TOP MANAGEMENT PERSONALLY ARE CONCERNED WITH AND COMMITTED TO THIS PROCUREMENT.

44. OUR COST CONTROL SYSTEM PROVIDES YOU A "DAILY LOOK THRU THE WINDOW OF THE OVEN".

45. MOST EXPERIENCE IN FIELD - (SHOW PHOTO OF EARLY PRODUCT).

46. STRONG TRACT RECORD FOR IN-THE-FIELD SUPPORT DURING INTEGRATION AND FLIGHT TEST.

47. INCREASING EMPHASIS ON HUMAN ENGINEERING AND THE MAN-MACHINE INTERFACE HAS REDUCED OPERATING COMPLEXITY.

48. CAREFULLY THOUGHT-OUT WORK-AROUND STRESSES EARLY PROBLEM DETECTION.

49. WE CAN BEST INTEGRATE THE MULTI-DISCIPLINARY TECHNOLOGIES REQUIRED.

50. LARGE, RIGID, LIGHTWEIGHT STRUCTURES, NEEDED TO PERFORM THIS MISSION ARE AVAILABLE IN OUR COMPOSITE MATERIALS TECHNOLOGY.

51. OUR SUBCONTRACTOR TEAM HAS BEEN CAREFULLY SELECTED TO ADD BREADTH AND DEPTH.

52. WE ARE CURRENTLY PERFORMING SIMILAR WORK FOR ______ THEREBY REDUCING RISK.

53. THIS PROGRAM ENHANCES OUR CAPABILITY IN AN ALREADY PROVEN PRODUCT LINE.

54. WE HAVE BEEN VALIDATED AGAINST CSCSC SINCE 1969.

55. WE UNDERSTAND THE PROBLEMS TO BE SOLVED AND THE METHODS REQUIRED TO MINIMIZE THEIR IMPACT.

56. AD THE INCUMBENT, WE OFFER COST SAVINGS REALIZED FROM AN ON-BOARD, TRAINED, AND DEDICATED FUNCTIONAL ORGANIZATION.

57. OUR SUPPLIERS AND SUBS DISTRIBUTE YOUR INVESTMENT COSTS TO ____ STATES AND ____ FOREIGN COUNTRIES.

58. OUR CONSERVATIVE APPROACH USES PROVEN DESIGN FOR UPGRADE RATHER THAN JUMPING TO NEW DEVELOPMENT.

59. WE HAVE LOWERED EQUIPMENT COSTS BY DESIGNING SYSTEM INTERFACES OPTIMIZE USE OF GFE.

60. FLEXIBILITY OF ACCOMMODATE SYSTEM INTERFACE MODS IS PROVIDED WITH "OUR COMPANY" FIRMWARE CONTROLLER.

61. A LOWER COST SOLUTION TO THE PROBLEM OF CONTINOUS ON-LINE FAULT DETECTION IS ____ PROCESSER ARCHITECTURE.

62. OUR DESIGN PROVIDES DESTRIBUTED SOLID STATE MICROPROCESSOR CONTROL OF XZZ SYSTEM WITH ALL THE REQUIRED FIRM WARE AND SOFTWARE.

63. OUR CURRENT IR&D HAS GIVEN US NEW, UNIQUE TECHNICAL APPROACHES.

64. OUR R&D APPROACH IS NOVEL AND PROVISING WHEN LINKED UP WITH TEST FACILITIES OF OUR COMMITTED SUBCONTRACTOR.

65. "OUR UNIQUE SYSTEM ACCURACY ON LONG FLIGHTS - DOWN TO LESS THAN 2 MM "PROVEN!"

66. SIGNIFICANCE OF OUR WORLDWIDE SERVICE LOCATIONS FOR LEVELS II AND III

67. OUTSTANDING ACCURACY ACHIEVED BY OUR INFLIGHT INSPECTION SYSTEM.
68. INFLIGHT REFUELING ACCOMPLISHED USING PRECISION AIRBORNE NAV SYSTEM.
69. WE ENCOURAGE THE AIR FORCE TO LOCATE PERSONNEL AT OUR PLANT TO WORK WITH US AND MONITOR OUR PERFORMANCE.
70. THIS PROGRAM REQUIRES THE SAME SKILLS, TECHNOLOGY AND EXPERTISE AS PROGRAM X WHICH WE DELIVERED AHEAD OF SCHEDULE.
71. WE WILL RETAIN THE VITAL ELEMENTS OF THE SYSTEMS JOB IN-HOUSE PROVIDING US THE NECESSARY CONTROL TO MEET COST AND SCHEDULE REQUIREMENTS.
72. OUR APPROACH PUTS MORE FUNCTIONS INTO HARDWARE TO REDUCE THE RISK ASSOCIATED WITH COMPLEX SOFTWARE.
73. OUR SOFTWARE SUB-CONTRACTOR HAS MORE SUCCESSFUL EXPERIENCE ON THIS TYPE OF SYSTEM THAN ANY OTHER COMPANY.
74. WE HAVE CO-LOCATED THE HARDWARE AND SOFTWARE DESIGNERS IN ORDER TO MINIMIZE RISK.
75. WE ARE LOCATED RIGHT OUTSIDE YOUR GATES, (OUR COMPETITORS ARE ACROSS THE COUNTRY).
76. THIS IS THE SAME TEAM THAT GAVE YOU THE HIGHLY SUCCESSFUL__________ PROGRAM.
77. SINCE THE L-2 IS SMALLER THAN THE L-1, IT IS THE ONLY AIRCARFT EVER BUILT WITH PROVEN GROWTH CAPABILITY.
78. AS EVIDENCE OF OUR LOW RISK APPROACH, WE HAVE SELECTED A SOFTWARE SUBCONTRACTOR THAT HAS SUCCESSFULLY DEVELOPED SEVERAL TURNKEY SYSTEMS ON THE NEW COMPUTER.
79. WE OFFER THE STABILITY OF A LARGE COMPANY WITH THE MANAGEMENT VIGOR AND EFFICIENCY OF A SMALL COMPANY.
80. AS EVIDENT BY DESIGN DETAILS PRESENTED IN THIS PROPOSAL, WE ARE READY TO IMMEDIATELY BEGIN IMPLEMENTATION.
81. WE HAVE DEVELOPED ENGINEERING MODELS AS "UP FRONT" PROOF OF DESIGN.
82. WE HAVE INITIATED DESIGN OF THE SYSTEM ON OUR OWN RESOURCES.
83. ANOTHER CONTRACTOR WOULD BE FORCED TO EXPEND ENORMOUS EXPENSE TO REPLICATE THE FACILITIES AND EXPERIENCE THAT WE POSSESS TO SOLVE THE PROBLEM.
84. BY VIRTUE OF OUR EXISTING HIGHLY TRAINED TEAM OF AVIONICS ENGINEERS AND TECHNICIANS, WE CAN DO THIS MODIFICATION IN HALF THE TIME AND TWICE THE PRECISION.
85. WE ALREADY HAVE AN INTEGRATED APPROACH TO LOGISTICS SUPPORT AND HAVE SINGLE POINT OF CONTROL FOR ALL ASPECTS OF INITIAL AND RECURRING VEHICLE SUPPORT.
86. OUR DESIGN MEETS OR EXCEEDS ALL RFP REQUIREMENTS WITHOUT SIGNIFICANT TECHNICAL RISKS.
87. SINCE ALL HARDWARE HAS BEEN BUILT AND TESTED SUCCESSFULLY, THE WEIGHT ESTIMATES ARE REALISTIC.
88. WE HAVE THE EXPERIENCE TO UNDERSTAND THE PROBLEM, THE TECHNOLOGY TO SOLVE IT, THE CAPACITY TO PRODUCE IT, AND THE MANAGEMENT TO CONTROL IT.
89. ENVIRONMENTAL IMPACT ANALYSES ARE ALREADY COMPLETE.
90. WE'RE USING "OFF-THE-SHELF" - THIS HEAD START REDUCES YOUR RISKS AND YOUR COSTS.
91. WE HAVE JOINED WITH NATIONALLY REPUTED EXPERTS FOR THIS JOB. OUR SUCCESS IS ASSURED.
92. WILL COST SHARE.

PROBLEM

HOW CAN A GOVERNMENT EVALUATION TEAM ASSURE ITSELF THAT ITS PERCEPTION OF A CONTRACTOR IS AN ACCURATE IMAGE OF THAT CONTRACTOR'S CAPABILITIES RATHER THAN AN ILLUSION PAINTED BY THE CONTRACTOR'S PROPOSAL?

PROPOSED SOLUTION

A TEAM OF SPO PERSONNEL WITH ROTATING ASSIGNMENTS AT EACH OF THE BIDDER'S FACILITIES -- STARTING PERHAPS 3 MONTHS PRIOR TO FINAL RFP -- TO DEVELOP IN-DEPTH KNOWLEDGE ABOUT EACH CONTRACTOR'S OFFERING.

FUNCTIONS OF THE ROTATING TEAM

O LEARN ABOUT EACH CONTRACTOR'S DESIGN: ITS STRENGTHS AND ITS WEAKNESSES

O LEARN ABOUT EACH CONTRACTOR'S PROPOSED PERSONNEL AND FACILITY AVAILABILITY

O DURING THE PROPOSAL EVALUATION, FUNCTION AS PART OF THE EVALUATION TEAM

O HELP PREPARE QUESTIONS ADDRESSING APPARENT WEAKNESSES IN DESIGN OR

MANAGEMENT OFFERING

PROBLEMS WITH THE "PROPOSED SOLUTION"

GOVERNMENT

- NEED MY PEOPLE AT HOME TO GENERATE RFP SPECS, SOW, ETC.
- CAN'T AFFORD 3 PEOPLE TDY FOR 6 MONTHS
- PLACES TOO MUCH OF EVALUATION RESPONSIBILITY ON ONLY 3 PEOPLE

CONTRACTORS

- LOVE TO HAVE YOU BUT NEED TIME TO COLLECT MY OWN THOUGHTS
- ROTATING ASSIGNMENTS BETWEEN CONTRACTORS MAY PRODUCE "TECHNICAL LEVELING"

PROPOSAL EVALUATION

JOSEPH W. KRUEGER

STAFF SOURCE SELECTION OFFICER

AIR FORCE SPACE DIVISION, LAAFS

Source selection, or more correctly for todays discussion, proposal evaluation is a simple, uncomplicated and logical process. Only people complicate the process.

Like any contest or sport, all are conducted according to a rule book, (Chart 1). In the case of proposal evaluation, the Department of Defense some years ago issued a directive 4105.62 to form the basis for a common approach to negotiated competitive acquisitions of major proportions. The Air Force implemented this direction with a regulation, 70-15 is the number. It contains basic guidance and requirements and paraphrases public law and the Defense Acquisition Regulation (DAR). Systems Command and the Space Division also implemented this regulation as well as producing guidance and policy for the structuring and content of the Request for Proposal which initiates the competitions in which industry engages. Systems Command has a pamphlet AFSCP 70-4 and the Space Division has a regulation number SDR 70-2 which provide policy and guidance for uniformity in RFP structuring.

While some new wrinkles in the overall process have been introduced by the Systems Command and the DAR set forth a new procedure for conducting the process known as the Four Step Procedure, (Chart 2). The basic technique or methodology of evaluation has really remained unchanged in the 20 years I have served the Government. We have, however, added other elements of consideration, a little differently, such as past perrormance, RFP tailoring, environmental awareness. Some things are more important today than they were years ago in making the final determination of a winner but the basic evaluation is still the same.

I also should mention that at the Space Division over a period of a number of years, (Chart 3), the offeror proposing the low dollar figure for an acquisition was coincidentally the winner of the competition less than one-third of the time. This is irrespective of contract type.

The part of the RFP which sets the stage for the proposals, is Part IV, Section L, which at Space Division is subdivided into an L-1 and an L-2. The latter is the proposal preparation instructions, and the former contains important notices about the proposal effort. This is where you are told what elements of the acquisition are to be discussed, how the text should be arranged in volumes, the limitation of type size and foldouts, and the number of pages you are expected to use for each volume, (Chart 4). In the case of mission assurance or sometimes called product assurance, we address, in addition to the risks involved, such topics as System Safety, reliability, maintainability, quality assurance and produceability, to name a few, (Chart 5). Any failure on your part to seriously and conscientiously address what is requested in this or other sections of the instructions can spell failure to win a competition. Generally it is a combination of many elements which spells defeat, but in a photo finish type of situation, just one element may be the straw that breaks the camel's back.

The next section or Section M of the RFP is where we set forth the ground rules for interpretation of your response. First of all we tell you what part of your proposal is the most important, such as technical, or whether all major areas are considered equally important. These are called areas of consideration, (Chart 6). We next tell you what the yardsticks are for measuring your response to a specific area. These are called criteria. Some common criteria are understanding of the requirements, soundness of approach, or risk minimization and most recently, since 1 Nov 79, past performance, (Chart 7). The relative importance of these are narratively set forth. Section M then lists in outline format the items of consideration and the subdivision, thereof, called factors of consideration. The order of precedence of these is also specified, (Chart 8). The outline headings or items and factors relate directly to what you were to supply in response to Section L-2, as well as to the tasks of the work statement and the work breakdown structure, and the contract data requirements list, or CDRL. Each area of consideration gets similar treatment with the cost proposal not

being rated or scored but a very vital part of the total package.

With both of us reading from the same rule book, we are in a position to not only evaluate your proposal, but to present facts and figures to a decision maker as to how well you responded to the various elements in terms of the criteria included in Section M, (Chart 9). How sound does your approach to various elements appear to be? How well have you recognized and faced up to the risk characteristics of approaches taken, and what is your track record for successfully accomplishing similar elements on other Government contracts?

In proceeding logically to accumulate and summarize the data from your proposals, an evaluator, qualified to assess specific elements, renders several pieces of documentation for each item or factor evaluated, (Chart 10). This is followed by providing a narrative which relates to the strong and weak points previously identified, (Chart 11).

Now, particularly for the weak points, or for other reasons, the evaluator will execute a clarification request or CR which later will be edited and provided the offeror. Some elements or presentations are not clear, blocking a full appreciation of what was presented. In other cases perhaps some backup data was not provided to substantiate an assertion, or the basis for a conclusion is not stated. Such is the nature of the CRs.

Another document of importance to the offeror which the evaluator completes is a deficiency notice or DN, (Chart 12). By definition, this is a portion of a proposal which fails to meet the requirements of the solocitation. In the case of the four-step procedure, these deficiencies will only be revealed to the offeror selected for negotiation of a definitive contract. Since only clarification requests are submitted to an offeror in the four-step procedure. It is incumbent on the offeror under this restrictive procedure to initially present his best and most comprehensive proposal. Deficiencies are the serious weaknesses. In the conventional selection process, the DNs are identified to each offeror and the offeror has an opportunity to correct them prior to the selection decision.

In addition, evaluator personnel cooperate with cost analysis personnel to develop risk assessments for specific elements of the requirement, (Chart 13). These form the basis for the Government's development of the most probable cost for each offeror's approach.

In addition to the evaluators, Government advisors and selected consultants are utilized, assuring a common understanding of the content of each proposal. All the documentation generated by the evaluators is reviewed by team chiefs, summarized, and important CRs and DNs, strong points and weak points elevated to the item and area level, (Chart 14). A final summarization is presented to the decision maker, utilizing color coded audio visual aid charts, along with a narrative explaining strong and weak points, CRs and DNs, all reflecting the responsiveness of the offeror in the terms of the original criteria contained in the solicitation, (Chart 15).

Offeror responsiveness to the mission assurance requirements are highlighted for the decision maker in the briefings provided. The briefings are based on the detailed source board report, which contains a comprehensive assessment of each offeror's response, (Chart 16).

Some thirty to forty-five days are consumed by evaluator teams in completing an initial assessment of the three to five proposals usually received. This includes review of initial evaluatons, challenges of findings, liaison with advisors and consultants, resolution of differences of opinion, refinement of narratives and summarizations for briefing presentations, (Chart 17).

Plans submitted for management-and-conduct of quality assurance receive the same treatment as the technical approach to satisfying a requirement. Any mission assurance approach provided by an offeror which essentially states that the requirements of a MIL SPEC will be satisified, won't create much excitement. For a manned orbiting flight, a missile or a

spacecraft, we want to know what unusual efforts, reviews or analyses will be conducted to enhance the assurance requirement. Naturally each offeror's track record and methodology are checked through contact with administrative offices for the prime and also for the major subcontractors. The team approach is vital.

With respect to Public Law 95-507, concerning small and disadvantaged businesses utilized by a prime, the over zealous support of the law should not jeopardize the mission assurance requirements of the program. The management control of subs is an important item for review during evaluations. Also, where mission assurance is cranked into an award fee plan, the evaluation team having that specific expertise, carefully assess all the implications of that inclusion. By the same token, any alternate proposal for satisfying mission assurance solicitation requirements is given the same quality of evaluation, utilizing the same criteria, as for the basic proposal. This evaluation is presented to the decision maker with all other trade-offs which may be advantageous to the Government.

I have deliberately included today the basic evaluation technique to assure you that mission assurance elements sometimes called "illities" and software receive the same thorough analysis as all other elements of a proposal. At Space Division we are steeped with the adage that for the want of a nail the shoe was lost, for the want of a shoe the horse was lost and for the want of a horse the battle was lost. There isn't a system deployed, launched or operated by this division, or an operational command, which doesn't require perfection of the highest order. Ground control and communication systems must be as reliable as their space borne cousins. The ground items can be repaired but back-up and alternates must be provided. Their procedures and design must keep a firm eye on the nail for that important shoe.

Since the evaluation techniques are widely known and procedures or ground rules are public knowledge, each offeror in a competition can evaluate himself as well as the surmised approach or presentation of his competitors and assess the likelihood of winning a competition. Remember, the low bidder doesn't always win. And whether or not a solicitation groups all mission assurance elements into one volume of a proposal is not an indication it will receive more or less attention from the decision maker. It's the quality of the response that gets attention, not the physical location of the presentation. Is your approach or presentation really better than that which your competitor can provide? Only each offeror can answer that question. Yours is not an easy task, namely expanding 10 or 20 pages of proposal instructions into 4 or 800 pages of proposal, and ours is not an easy task, condensing those pages into a one to four hour briefing and written analysis of the salient facts. Perhaps in the discussions today and tomorrow some improvement in the evaluation technique and presentation may be developed which will benefit both industry and the Government.

SOURCE SELECTION REGULATIONS

DODD 4105.62	6 JAN 76
AFR 70-15	16 APR 76
AFR 70-15 AFSC SUP 1	18 FEB 77
AFR 70-15 SAMSO SUP 1	19 APR 79
SAMSOR 70-2	19 OCT 78
AFSCP 70-4	1 MAY 78
DAR 3-500	1 JUL 76
DAR 3-508	1 JUL 76
DAR 3-805	1 JUL 76
DAR 4-107	1 SEP 78

COMPARISON

CONVENTIONAL

1. COMPLETE PROPOSAL (TECHNICAL, COST, MANAGEMENT)
2. EVALUATION
   COMPETITIVE RANGE DETERMINATION
3. DISCUSSIONS/NEGOTIATIONS
4. BEST AND FINAL OFFERS
   SIGNED CONTRACTS
5. SELECTION AND CONTRACT AWARD
   NOTICE TO UNSUCCESSFUL OFFERORS
6. DEBRIEFINGS

FOUR-STEP

1. SOLICITATION
   TECHNICAL PROPOSALS
   EVALUATION AND LIMITED DISCUSSIONS
2. COST PROPOSALS W/TECHNICAL UPDATE
   COMPETITIVE RANGE
   EVALUATION AND LIMITED DISCUSSIONS
3. COMMON CUT-OFF FOR REVISIONS
   SELECTION OF APPARENT WINNER
   NOTICE OF UNSUCCESSFUL OFFERORS
4. NEGOTIATIONS AND CONTRACT AWARD
   DEBRIEFINGS

BASIS FOR AWARD-SOURCE SELECTION ANALYSIS

	FFP	FPIF	CPIF/CPAF	CPFF	TOTAL
CONTRACTS AWARDED	[illegible]	2	[illegible]	[illegible]	[illegible]
CONTRACTS AWARDED TO LOWEST OFFEROR	1	1	1	2	[illegible]
PERCENT AWARDED TO LOWEST OFFEROR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

THE ABOVE STATISTICS APPLY TO [illegible] SOURCE SELECTION ACTIONS

MISSION ASSURANCE

PROPOSAL PREPARATION INSTRUCTIONS

MISSION ASSURANCE VOLUME V

- QUALITY ASSURANCE
- MAINTAINABILITY
- SYSTEM SAFETY
- RELIABILITY
- PARTS, MATERIAL, PROCESSES

MISSION ASSURANCE

PROPOSAL EVALUATION, SPECIFIC CRITERIA

(AREA ITEMS)

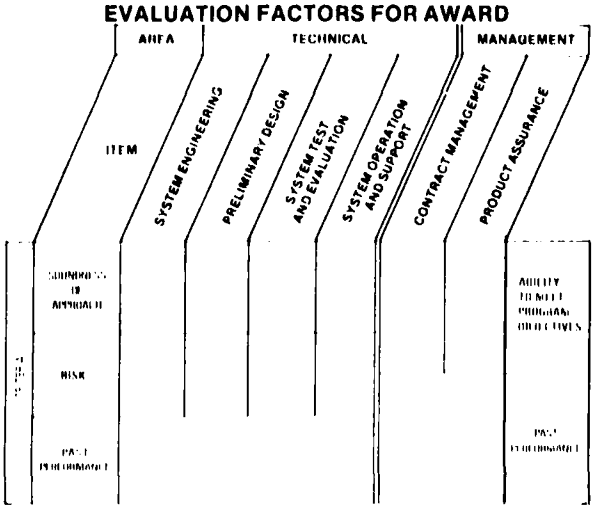
TECHNICAL AREA

- SPACE VEHICLE SYSTEM (ITEM)
- TEST AND EVALUATION
- SYSTEMS ENGINEERING
- MISSION ASSURANCE
- SUPPORT OPERATIONS & SERVICES
- SPECIAL TEST EQUIPMENT

EVALUATION CRITERIA

- PAST PERFORMANCE
- UNDERSTANDING OF REQUIREMENTS
- SOUNDNESS OF APPROACH
- MERITS OF DESIGN
- RISK MINIMIZATION
- PRODUCTION CAPABILITY
- SATISFACTION OF REQUIREMENTS
- VALIDITY OF ANALYSIS OF TRADE STUDIES

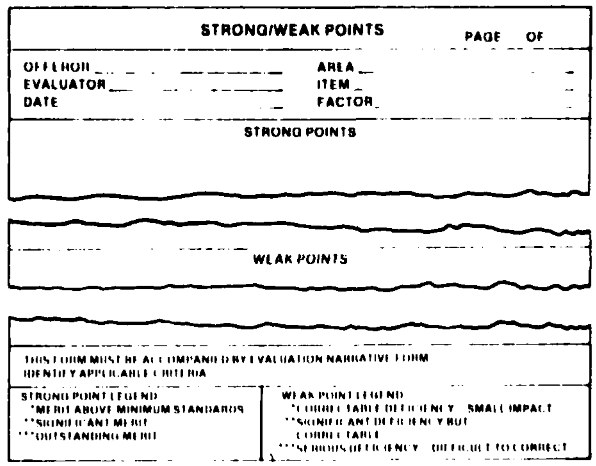
EVALUATION FACTORS FOR AWARD



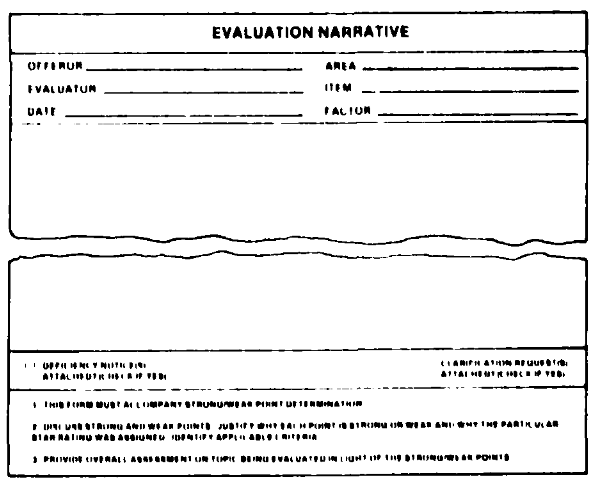
AREAS, ITEMS, FACTORS

	1.1	SATELLITE AREA	1.2	SYSTEM AREA
ITEM	1.1.1	COMMUNICATIONS	1.2.1	MECHANICAL DESIGN
ITEM	1.1.2	POWER	1.2.2	PRODUCT EFFECTIVENESS
ITEM	1.1.3	TT&C	1.2.3	SYSTEMS ANALYSIS
ITEM	1.1.4	ATTITUDE CONTROL	1.2.4	PAYLOAD INTEGRATION
	1.1.1	COMMUNICATIONS (ITEM)		
FACTOR	1.1.1.1	DESIGN ANALYSIS		
FACTOR	1.1.1.2	EARTH COVERAGE ANTENNA		
FACTOR	1.1.1.3	NARROW BEAM ANTENNA		
FACTOR	1.1.1.4	TRANSPONDER		
	1.1.1.4	TRANSPONDER (FACTOR)		
SUB FACTOR	1.1.1.4.1	RECEIVER FRONT END CIRCUIT		
SUB FACTOR	1.1.1.4.2	MID CHANNEL CIRCUIT		
SUB FACTOR	1.1.1.4.3	OUTPUT CIRCUIT		

PROPOSAL EVALUATION



PROPOSAL EVALUATION (CONT)



PROPOSAL EVALUATION (CONT)

CLARIFICATION REQUEST (CR)

OFFEROR ____________ AREA ____________
EVALUATOR ____________ ITEM ____________
DATE ____________ FACTOR ____________
RFP REFERENCE ____________ PROPOSAL REFERENCE ____________

PREPARE ONLY FOR INFORMATION REQUIRED TO FAIRLY EVALUATE THE PROPOSAL. IS SUBSTANTIATION DATA REQUIRED? WHAT IS MISSING THAT WOULD CLARIFY PROPOSAL ELEMENTS? HOW SHOULD CR BE WORDED FOR SUBMISSION TO OFFEROR?

DISPOSITION APPROVED DISAPPROVED	CHAIRMAN	DATE	CONTROL NUMBER

PROPOSAL EVALUATION

DEFICIENCY NOTICE (DN)

OFFEROR ____________ AREA ____________
EVALUATOR ____________ ITEM ____________
DATE ____________ FACTOR ____________
RFP REFERENCE ____________ PROPOSAL REFERENCE ____________

REMINDER: DEFICIENCY MUST BE ON STRONG/WEAK POINT FORM AND DISCUSSED IN EVALUATION NARRATIVE. DEFICIENCIES WHICH MAY CAUSE A CHANGE (+ OR −) IN OFFEROR'S PROPOSED HOURS/COST *EXCEEDING HOURS/COST LIMIT SPECIFIED IN EVALUATION GUIDE* MUST BE ACCOMPANIED BY A RISK ASSESSMENT FORM

1. WHAT IS DEFICIENT?
2. WHY IS IT DEFICIENT?
3. WHAT IS IMPACT IF NOT CORRECTED?
4. HOW SHOULD DEFICIENCY BE WORDED FOR SUBMISSION TO OFFEROR?

DISPOSITION APPROVED DISAPPROVED	CHAIRMAN	DATE	CONTROL NUMBER

PROPOSAL EVALUATION (CONCL)

RISK ASSESSMENT

OFFEROR ____________ DEFICIENCY NOTICE NO ____________
SOW TASK NO ____________ TASK TITLE ____________

RISK ASSESSMENT HIGH MED LOW NONE
IDENTIFY PROBLEM AREAS
- SOW TASK NOT COMPATIBLE WITH TECHNICAL PROPOSALS/SCHEDULE
- MANLOADING & SPREADS NOT COMMENSURATE WITH EFFORT
- MISSING PROGRAM TASKS/HARDWARE
- MATERIAL QUANTITIES, NUMBER OF TRIPS, COMPUTER HOURS NOT COMMENSURATE WITH EFFORT
- OTHER (DESCRIBE) ____________

RECOMMENDED REVISIONS (MUST CORRELATE TO RISK ASSESSMENT)
CONTRACTOR PROPOSED HOURS ____________
SSEB ESTIMATED HOURS ____________
DELTA ____________
RATIONALE/NARRATIVE (USE ADDITIONAL SHEETS AS REQUIRED)

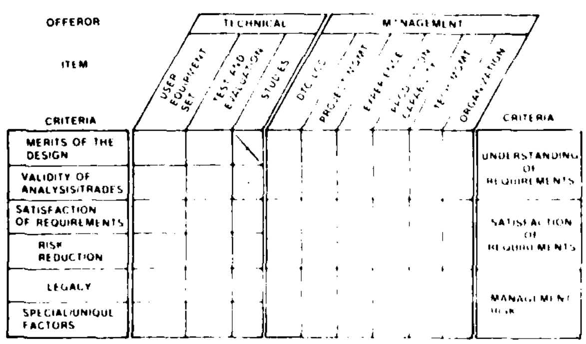
SUBMITTED BY ____________ (PANEL) ____________
REVIEWED BY ____________ APPROVED BY ____________

PREPARE ONLY WHEN DEFICIENCY WILL CAUSE A CHANGE (+ OR −) IN OFFEROR'S PROPOSED HOURS/COST EXCEEDS HOURS/COST LIMIT SPECIFIED IN EVALUATOR'S *GUIDE*

COLOR CODE FOR BRIEFING CHART

BLUE	— *EXCEEDS SPECIFIED PERFORMANCE OR CAPABILITY* AND EXCESS IS USEFUL, HIGH PROBABILITY OF SUCCESS; NO SIGNIFICANT WEAKNESS.
GREEN	— AVERAGE, MEETS MOST OBJECTIVES; GOOD PROBABILITY OF SUCCESS; DEFICIENCY CAN BE CORRECTED.
YELLOW	— WEAK; LOW PROBABILITY OF SUCCESS; SIGNIFICANT DEFICIENCIES, BUT CORRECTABLE.
RED	— KEY ELEMENT FAILS TO MEET INTENT OF RFP.

PROPOSAL EVALUATION BRIEFING AID

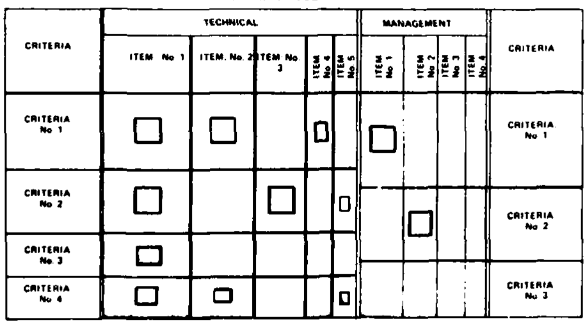


EVALUATION BRIEFING

- BACKGROUND CHARTS
- OVERVIEW OF OFFERS
- STRONG AND WEAK POINT CHARTS
- NARRATIVE SUPPORT OF CHARTS
- COLOR CODE CHARTS
- CLARIFICATION / DEFICIENCY DATA
- DISCUSSION/NEGOTIATION IMPACT
- COST DATA
- PREAWARD SURVEY, AUDIT AND PAST PERFORMANCE DATA
- CONTRACTUAL DATA
- RISK ANALYSIS
- SUMMARY

OFFEROR A

SUMMARY ASSESSMENT



NOTE - WEIGHTED CHART FOR SSA
- COLOR INSERTS USED TO DEPICT INITIAL COLOR ASSIGNED
- COLORS USED AND DEFINITIONS THEREOF MUST CONFORM TO AFR 70-15/SAMSO Sup 1

PROPOSAL EVALUATION

Mr. Clen Neehan
HQ NASA

INTRODUCTION

I'd like to start out by saying that I find the concept of mission assurance particularly important to NASA as an agency. This importance traces back to the beginnings of NASA when the mission of the agency was the national priority and required the marshalling of much of the scientific, engineering, and management talent in the country into an effort that reached its culmination with man's first steps on the moon. This effort required an approach that utilized the expertise of government, industry, and university personnel is developing a workable program that would succeed in accomplishing the assigned mission. The program also fostered within NASA an evaluation approach that, notwithstanding the shifting of national priorities, has carried forth to the present.

The evaluation approach has always had as its main focus the necessity to look into the future in order to determine the steps that must be taken now to ensure a successful space flight. When space was an unexplored horizon, each step was a new one and had to be carefully weighed before proceeding into the next step. The uncertainties inherent in this exploratory process coupled with the factors of prestige gained from "firsts" is space and safety for manned space flights tended to override the importance of cost factors.

The evaluation approach presently being used still maintains the main focus of looking into the future, however, these has been subtle shift in emphasis to what I would call "cost effective space flight." This shift has had an effect on the evaluation approach but has not forced a change in it, thereby validating the thought processes of those who developed an approach that has remained flexible and responsive to the changing needs of the agency. I will now enter into a "nuts and bolts" discussion of this approach and comment on its development and implementation within NASA.

SOURCE EVALUATION BOARDS (SEBs)

In my experience as a contract negotiator and contracting officer, I have often characterized the source evaluation process as a method by which a subjective judgment is made as objectively as possible. This highly simplified definition helps me in understanding the reasons behind the various source selection processes that have been developed at different government agencies and in different industrial concerns. Although many similarities exist in structure, the differences come about because the process is basically one of decision-making, and most organizations differ in their process of making decisions. Thus, evaluation boards normally have rigid structural requirements concerning who will make the decision, what regulations or laws must be followed, what areas of proposals will be scored, etc. These black and white or do and don't areas are fairly similar within organizations and form a perimeter within which the Source Evaluation Board may operate. Within that perimeter, however, the judgment f[illegible]rs that lead to gray or shaded areas of distinction take precedence. The handling of these gray or shaded areas is the factor that determines the success of the process and characterizes it to those outside of the organization.

Within NASA, the formal process of source evaluation has been documented in the NASA Source Evaluation Manual. The following excerpts are taken from the Preface and Foreward to this manual:

> "The source evaluation and selection process covered by this manual exemplifies our efforts to emphasize the application of sound judgment to the problem of source evaluation."

> "This manual provides general and specific guidance ... in the evaluation of competing companies and their proposals in negotiated procurements."

"Its (the manual) intention is to encourage the exercise of judgment in the many important aspects where it is essential, and to prescribe a set process where experience has shown it to be required."

"Users (of the manual) are expected to apply common sense in determining where appropriate variations and adaptations are necessary in individual situations, provided that these do not constitute a departure from basic concepts and intent."

"The Manual is organized so as to provide substantive and procedural guidance."

As can be seen by these excerpts, there is a realization of the gray areas in which an SEB operates, a realization that allows for a different character to be demonstrated by each individual SEB.

Within an evaluation process, there are several key indicators as to the direction that the Board will take or the areas that the Board will consider important. Of course, the evaluation factors and their relative order of importance are keys to individual procurements but, on a generalized level, the composition of Boards and their place in the decision-making process emphasizes the policies of the organization. At NASA, line management is specifically tasked with responsibilities for decision-making while line and staff management work together to ensure proper functioning of the process. Thus, one could expect an evaluation bias weighing heavily on the technical aspects of a proposal. This bias is further reinforced by the following excerpt from duties of the Board:

"Evaluate the various features of the proposals that, together, determine how well each proposer might fulfill mission suitability requirements; and to combine these judgments into an integrated assessement of relative probable performance."

The Boards are comprised of an appropriate mix of qualified management, technical, scientific, contracting, and business experts and shall normally not exceed seven voting members, including the Chairman. However, it is desirable that voting members of the Board include people who will have key assignments on the project to which the procurement is directed Finally, there are normally two major committees set up within an SEB, a technical committee to evaluate and score proposals against mission suitability criteria and a business management committee to study and analyze costs, evaluate experience and past performance, and analyze any other factors that may be pertinent to the selection. The Board does not make recommendations to the Source Selection Official, it reports findings that are scored for mission suitability and commented on for cost and other factors. Although the fact that mission suitability is scored should not be overrated, since the Selection Official must consider all factors in making the selection, it remains a prime factor in determining the likelihood that an offeror can deliver a product that will meet the Government's stated requirements.

SEB Operating Procedures

The official activities of a Board for a particular procurement will commence upon receipt by the Chairman of the letter establishing the Board and designating its members. The Board then carries out administrative tasks to ensure that members understand the procurement, that adequate personnel and expertise are available, that all prior relevant work is collected, and that a list of qualified sources is developed. The Board then reviews in detail the paperwork generated by the project office that includes the procurement plan, project plan, and all areas of the RFP. The primary objective at this time is to ensure consistency of of requirements in all steps leading up to the release of the RFP. After release of the RFP, a pre-proposal conference may be held. Upon receipt of proposals, the contracting officer sends all proposals,

unopened, to the SEB Chairman. The Board convenes promptly and the evaluation begins, normally involving the committees. The committees will first identify any unacceptable proposals which will receive no further evaluation and then make a detailed review of the acceptable proposals, the results of which will be presented to the Board. The Board will then make a competitive range determination and conduct a final evaluation to arrive at findings to be presented to the Source Selection Official with final scoring on mission suitability factors and reports on the analyses of cost and other factors.

Considerations

Prior to the appointment of an SEB Chairman and Board Members, there has been an undefineable period during which basic and advanced research has been conducted and has pointed out a need that can be satisfied through the use of space technology or that state-of-the-art advances in space technology can satisfy. At NASA, these normally take the form of new or improved instruments, use of spacecraft to collect data, or transmission of data from space to users of that data. One of the first considerations facing an SEB is the assimilation of that prior research. This is not a formidable task since selection of members for the SEB considered familiarity with the project. However, the Board must evaluate its own ability to handle all facets of the upcoming procurement and ensure that it has sufficient expertise to cover these facets.

The requirements review process takes place place in two stages. The first of these is a consideration of program goals as developed from a technical and fiscal standpoint. The second is a detailed review of the SOW and RFP to ensure that they conform to these goals. Within the RFP, the evaluation criteria and their relative order of importance are prime indicators of where the Board has placed their emphasis. NASA normally uses a 1000 point scoring system with the major mission suitability areas being: (1) understanding the requirement; (2) management plan; (3) excellence of proposed design; (4) key personnel; and, (5) corporate or company resources. Each of these areas is weighted by the Board as they develop a general plan for scoring that will be used by the committees. There is no format for scoring plans and they can vary for each SEB. Weightings are not disclosed below the level of the SEB. The Board also reviews the unscored areas of cost, experience and past performance, and other factors to determine if there is any specific information that may be required in the proposals over and above that normally required.

The considerations of the period after receipt of proposals are the initial and final evaluations. The final evaluation will normally include written or oral discussion, identification of the strengths and weaknesses of each proposal, identification of the capabilities of the offerors, and the best collective and objective judgment of the SEB in arriving at its findings.

SUMMARY OF ISSUES AND RECOMMENDATIONS

RFP/SOW COMMUNICATIONS

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Early Interchange

Issue

Information exchange on major contracts should be initialed earlier.

Recommendations

- o ASFC to establish formal guidelines for all buying divisions to implement industry conferences to promote interchange of information with industry prior to development of business strategy for PMD (Program Management Directive).
- o Early release of draft-RFPs and industry participation in "Murder Boards" should be continued.

2. Proposal Evaluation

Issue

Proposal evaluation criteria is not sufficiently stated in RFPs for the contractor to understand program priorities.

Recommendations

- o Procurement evaluation panels should insure evaluation criteria contains sufficient detail to enable the contractor to properly prepare his proposal. Continued participation of industry in RFP murder boards will assist in achieving this objective.

3. Bidders List

Issue

Utility of bidders lists and their cost effectiveness is questioned. There is too much duplication of resources involved in the individual maintenance of local bidder lists.

Recommendation

- o Recommend the local bidders lists be replaced by SBA's procurement automated source system (PASS) for small businesses and/or other centrally maintained lists.
- o Eliminate bidders lists for large businesses or centralize.

4. Use of CBD's (Commerce Business Daily).

Issue

CBD should be used more extensively to facilitate early government/industry communications.

Recommendations

- o Buying office should be instructed to use the CBD as the primary device for soliciting responses to RFP's. Contents of CBD submissions should be sufficiently specific to adequately inform industry of the nature of the procurement.
- o Consideration should be given to electronically transmit CBD submissions via the GSA administrative reporting system.

5. Zero Base RFP/SOW

Issue

The present practice of specifying specifications and standards are apparently inhibiting contractor responses with respect to how they are applied. They evidently feel that they will be considered non-responsive to the RFP, consequently the government is not receiving contractor inputs with respect to tailoring specification requirements.

Recommendations

- o Proposal instructions for draft

RFP's should adopt a zero base concept of applying contract specification and standards which essentially asks the contractor to provide his tailored application of of each applicable specification and standard that he feels are necessary to meet the essential needs of the program/contract.

6. Lower Tier Specifications

Issue

The preponderence of lower tier specification that are applied to government contracts through the "referencing down" procedure is causing much "gold plating" and creating now essential work by contractors. The SPOs do not have the time or manpower to review the lower tiers specification to the level required for adequate application.

Recommendations

- A project should be initiated at DOD level to develop a specification/standards traceability matrix (preferably an automated program) which would identify the relationship(s) of all lower tier specification to the extent they are applicable to the parent specification and the identification of redundent requirements.

7. Correlation of Contract Requirements.

Issue

RFPs are not properly organized for ease of proposal preparation and evaluation.

Recommendations

- SOW, WBS, evaluation criteria, and volume organization should all be correlated. Proposals should be formatted with same correlation. Requirements should should be listed by priority, cirticality and tradeability.

8. Program Background Information

Issue

The government rationale for requirements are frequently not made known to contractors.

Recommendations

- Buying offices should be encouraged to establish a program library of information studies, and analyses which form the basis for requirements. Contractor accessability to be available when CBD announcement released.

9. Lessons Learned

Issue

Government inter-agency communications are too limited. Interorganizational lessons learned are not readily available and therefore not used. Contract administrations offices can be a part of the acquisition team to facilitate early communication with and about contractors.

Recommendations

- Contract administration services (CAS) and buying divisions should emphasize the desireability of contract administration offices (CAO's) receiving draft RFPs.

- Feasibility of establishing a centralized lessons learned data bank be investigated.

WORKSHOP K

PERSONNEL MOTIVATION, TRAINING AND EXPERIENCE SHARING

Co-Chairmen

Mr. James M. Teresi
Director, R&C Data Center
Electronics & Optics Division
The Aerospace Corporation

Mr. David W. Grimes
Project Manager
Delta Project
NASA Goddard Space
Flight Center

Mr. F. Cecil Hill
Corporate Manager
Improvement Programs
The Hughes Aircraft Company

WORKSHOP PAPERS

"Training & Quality Awareness"	Mr. Vince Mancino, RCA
"Motivation Programs" – Honeywell	Dr. Mike Donovan, Honeywell
"Motivation Programs – Quality Circles" Westinghouse Electric	Mr. Ed Mitchell Westinghouse Electric
"Quality/Productivity Motivation" Martin-Marietta	Robert Lozano Martin-Marietta
Communications Network for a Major Program	Mr. David Grimes, NASA

Training and Quality Awareness
by
V. J. Mancino

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Princeton, N.J. 08540

Introduction and Need for Training

Good quality is good business and good politics. Ignoring quality invites higher reject rates and attendant higher costs thereby risking loss of business. After all the recognized disciplines of reliability have been observed during the design phase, one must still insure that the product is built as intended by the design. There are many ways to do this, but this paper concerns the importance of training in promoting quality and the role that training plays in both motivating the employee and promoting an atmosphere of quality awareness. The Training and Indoctrination Program used at RCA Astro is used as the vehicle to illustrate these concepts.

With the complexity of the designs in the space industry, resulting from increased functional demands coupled with more stringent space, weight, and power requirements, greater demands have been placed on skills of manufacturing and test personnel. The increased demands have placed a premium on building the quality into the product, checking the quality of the product, and measuring the quality trends. After the design process is completed, the building of a quality product requires sound procedures, good equipment, a cooperative management attitude, a conducive work environment, good material, and skilled people. The people are the integrating element of all these ingredients. It follows, then, that to improve quality, the people must be skilled, aware of quality, and properly motivated.

A well planned Training, Certification, and Indoctrination Program improves employee skills, increases the employee's awareness of quality, may enhance employee motivation, and improves productivity and quality for the company. A good training program must satisfy the individual's fundamental psychological needs and human motivation desires. When these requirements are met, greater job satisfaction and reduced personnel turnover occurs.

Training is invoked most frequently on the new employees or for an employee intending to perform specific processes for the first time. The purpose of this training is to:

1. Provide the individual with the skills and knowledge necessary to certify for processes that are critical to product quality such as soldering, welding, and crimping operations.

2. Impart specific skills required to fabricate, inspect and test a quality product.

3. Provide appreciation for the importance of individual operator tasks.

4. Emphasize the importance of group or team effort for quality and productivity.

Indoctrination as used here is invoked most frequently on current employees. The purpose of this indoctrination is to:

1. Provide the employee an understanding of division policy and approaches to achieve and accomplish specific tasks and objectives.

2. Make employees aware of changes to specific policies, objectives, or procedures.

3. Promote awareness for quality and/or other items of current concern.

Both the Training and Certification of operators and testers, and the Indoctrination of employees in specific topics are the responsibility of Quality Engineering.

Training and Certification Program for Operators and Testers

The successful completion of job related Training and Certification courses is mandatory at Astro for manufacturing operators and test personnel of flight hardware.

Formal training courses are provided by Astro's Training Center to teach employees the skills necessary to certify for specific operations.

The Training and Certification program used at RCA Astro has the following features and requirements:

1. Formally required by Division Policy in the Division Operating Instructions.

2. Training in selected areas for certification.

3. Successful completion is a condition for employment.

4. Training consists of:

   a. An overview stressing importance of specific skills to the end product and to the division.

   b. Detailed instruction (demonstration of how to) by instructor.

   c. Practical experience - Individual's performance of task.

   d. Critique of individual's performance stressing weak points or commending good performance.

5. Initial certification is limited to a trial period of 60 days to assess work in the assembly environment.

6. Permanent certification by certification card.

Certification is recognized only after the operator has achieved satisfactory job performance for sixty days as determined by his supervisor, Training Center personnel, and by the Defect Summary which is discussed later.

A variety of courses are offered by the Training Center at RCA Astro to achieve the desired results. Each manufacturing operator must take a basic 40 hour Training Course called Descriptive Assembly Fundamentals plus one other course for the specific area where the operator is assigned. The basic course is designed to teach the operator the rudimentary knowledge and skills he needs to be employed in RCA Astro's Product Operations. The course also attempts to motivate the operator by instilling pride in his work, and by showing him how his efforts contribute and are important to the final product.

The courses are taught on site in a designated training area secluded from the normal hustle encountered in the manufacturing environment. Each operator is issued a set of tools, materials, and shown how to use them at a work bench similar to those used in the manufacturing assembly area. The learning experience is primarily a work experience where the operator is taught to utilize specific processes or operations. The classes are limited to ten student operators so that the instructor can provide individual attention as required.

A list of the most frequently offered courses is shown in Table 1. Several of the courses shown such as Operation of Overhead Cranes and Multipin Connector Mating/Demating are for Testers rather than manufacturing assembly operators.

Throughout the instruction period the employee's work is critiqued and he is shown how to improve his quality. The employee is encouraged to ask questions and repeat any steps he feels need improvement. The training sessions are arranged to include some training films, slides, or lecture type instruction away from the work benches.

For each student the instructor completes a Training Report as shown in Figure 1. Each item on this report is discussed with the student. A "Satisfactory" must be obtained for each item for the student to be certified. Following the completion of the course, the student either receives a Temporary Certification valid for 60 days or is judged as not qualified for certification. In the latter case, the student cannot be considered for employment as a manufacturing assembly operator. With a "Satisfactory" completion the student is given a Certification Card as shown in Figure 2. This initial card will have an expiration date of 60 days.

Following completion of the training courses, the student is released to Product Operations for on the job experience and training.

TABLE 1. TYPICAL CERTIFICATION COURSES OFFERED BY TRAINING CENTER

Course Hours	Recertification Hours	Course Title
40	-	Descriptive Assembly Fundamentals
40	16	Hand Soldering Fundamentals NHB5300.4 (3A)
16	8	Soldering/Wiring Verification
8	1	Close Circuit Reflow Soldering
4	-	Operating of Overhead Cranes
40	4	Microcircuit Soldering
16	1	Wave Soldering
8	1	Solar Cell Assembly Interconnections
4	1	Solderless Wirewrap
32	1	Modular Induction Brazing
40	2	Semi-Automatic Buttonhead Welding Fundamentals
40	2	Manual Buttonhead Welding Fundamentals
40	2	Resistance Cross Wire Welding
16	2	Parallel Gap Welding
24	2	Back Plane Welding
40	4	Plastics Application Technology
As Req'd	As Req'd	On-the-Job Training Format
24	4	Buttonhead Welding (Inspector)
4	-	Multipin Connector Mating/Demating

The new employee is encouraged to keep in contact with the Training Center and ask questions, if he is having difficulty or is having a confidence crisis. Training personnel also make it a point to visit the new employees on the Product Operations floor to see how they are doing. After sixty days of on-the-job training, if the results are still satisfactory, the new employee is given a permanent Certification Card.

This certification remains in effect until an event occurs that requires the employee to be recertified. Recertification is mandatory if any one of the following events occur:

1. Quality of work unsatisfactory in specific instances.
2. Operator defect summary indicates an unsatisfactory trend.
3. Work interruption for greater than 30 days.
4. New techniques developed which require different skills.
5. Operator upgraded to an inspector.

Maintaining Product Quality and Quality Awareness

After the employees are fully trained, both the progress of each operator and the product quality is constantly assessed. This is done by the use of the following techniques:

1. Product is built to certified processes.
2. Product is inspected at key toll gates by certified inspectors.
3. Follow-up inspections are performed by Training Center personnel.
4. Flow of product to process steps and inspection points is defined in a Fabrication Procedure Record (FPR). This is a controlled specification.
5. Deviations are documented per a Flow Alteration Record (FAR) prior to implementation.
6. Testing of product per a test procedure, which is also a controlled specification.
7. Defect reporting system for inspection results.
8. Test discrepancy reporting system for testing results.

The above techniques are designed to be formal and to keep each employee aware of the importance for good quality. In addition to the above Indoctrination sessions for specific topics of concern are given to selected groups when warranted. Specific examples include:

1. The showing of quality oriented training films when recommended by the Training Center or Management.

2. Specific topics of concern to the Program Management Offices.

At each inspection point, Quality Control inspects the product or process step and determines its acceptability to specified requirements. If the inspected item is judged not acceptable, then a Unit Evaluation Report (UER) is prepared. If the defect is judged to be valid by the QC leader, the defect is discussed with the Manufacturing Leader and the Operator. At the discretion of the QC leader the defect may also be reviewed by Quality Engineering. The defect is also inputted into a Computer Data Bank for later recall and Management visibility. The above follows the flow shown in Figure 3.

a. Quality Awareness via Defect Reporting

The Defect Reporting System shown in Figure 3 has been found to be very effective as used at RCA Astro. It has the following salient features:

1. Operator performance is available on any given task.

2. Training personnel can approach operator independently.

3. Promotes team approach rather than an individual contest.

4. Provides management with various analyses:

   - By operator
   - By inspector
   - By work center
   - By program
   - By item manufactured
   - Accept/reject per total inspections

5. Provides data for development of future plans.

Computer reports are issued on both a weekly and a monthly basis. The weekly reports are very detailed and specific regarding the defects incurred. The monthly reports are formatted to provide visibility of trends indicative of problems that might be occurring. These reports provide a data base so that Quality Engineering or Product Operations may institute corrective actions.

b. Quality Awareness via Test Discrepancy Reporting

After the product is built, and inspected, it is subjected to its Flight Acceptance Testing and all test discrepancies are formally reported. Each discrepancy is formally acted upon and dispositioned by a Test Review Board. The discrepancy is then coded and inputted into a computer data bank so that various trends can be detected. The TDR System is not primarily a barometer for measuring training effectiveness and is only mentioned here for completeness. Nevertheless, many useful trends have been detected by this system and as a result changes in processes and new training courses have been implemented. As an example on several major programs it was noted that an excessive number of multipin miniature connector failures were being encountered in the Integration area. The failures were broken pins, bent pins and chipped insulation. Analyses were conducted and it was concluded that the problem was not a generic parts problem but operator related. It was decided to have the Training Center develop a Connector Mate/Demate course in which selected Test Operators were certified and the mate/demate of connectors was restricted to the certified test operators. The discrepancies immediately and dramatically dropped to a lower plateau. Even though the improvement was gratifying each subsequent discrepancy was a constant source of irritation to the Program Office. So additional steps were instituted which required:

1. A Mate/Demate Log

2. Observance of the Mate/Demate by the Test Leaders, and

3. A Quality Control check of all connectors mated and demated before power turn-on.

The result of instituting a Training Course for Certification plus surveillance dropped the discrepancies to essentially zero.

Quality Awareness Indoctrination Sessions

As previously mentioned in addition to formal Training courses intended for Certification of operators, there is also a regular program of quality awareness indoctrination sessions. These sessions are primarily for engineering and test personnel and are intended to:

1. Make the employee aware of Division policy on selected topics important to his specific assignments.

2. Provide specific information as to why certain practices are necessary, e.g. clean areas.

3. Instruct employees on how to perform specific tasks, e.g. complete Test Discrepancy Reports, Engineering Change Notices.

4. Provide information when major changes occur in Division Operating Instructions.

5. Provide feedback when a Program has immediate needs or concerns.

6. Impart an attitude of Quality Awareness to the employee.

7. Obtain feedback from the employee.

These sessions are the responsibility of Quality Engineering. They are held in a relaxed environment where employees are encouraged to ask questions, express their opinions, and explain any difficulties encountered. Each session generally lasts about one to two hours each depending upon audience reaction. The goal is to make each topic available once a year, unless events warrant more frequent scheduling. Attendence at a session for any one topic is generally limited to twenty-five people.

The Quality Awareness training sessions have been found to be an important source of employee suggestions to improve procedures where they have encountered problems. The success of the program has resulted in many employee suggestions, which have been incorporated in subsequent revisions of the Division Operating Instructions.

Table 2 lists some of the typical Quality Awareness sessions regularly offered by Quality Engineering.

Summary

Quality awareness and motivation can be provided and enhanced by training. This requires a planned approach and an atmosphere conducive to employee pride of workmanship. The starting point is formal courses for training in basic skills and certification in critical processes. In addition quality awareness sessions are required to make employees aware of policy procedures. These are required on a regular basis and on special occasions when warranted for special topics.

After the training and certification a continuous surveillance is required. The checks provided by the implementing of a Defect Reporting System and the Test Discrepancy Reporting System provides a data base which is useful to both management for visibility and planning, and to the employee for maintaining his motivation and as a constant reminder to be aware of quality.

TABLE 2. TYPICAL INDOCTRINATION SESSIONS OFFERED BY QUALITY ENGINEERING

Topic
RECEIPT, INSPECTION & STORAGE OF FLIGHT TYPE GFE
CONTROL OF CONFIGURATION AND DESIGN TECHNICAL DOCUMENTS
ENGINEERING CHANGE & STOP WORK NOTICES
CONFIGURATION MGMT OF PRODUCT RELATED COMPUTER PROGRAMS
FABRICATION & ASSEMBLY CONTROL DOCUMENTS
INTEGRATED SPACECRAFT TESTING
CONFIGURATION ACCOUNTING AT SYSTEM OR SPACECRAFT LEVEL
REPORTING OF TEST PROBLEMS AND DISCREPANCIES
CONTROLLED CLEAN AREAS
CERTIFICATION OF PERSONNEL FOR SPECIAL PROCESSES
PROJECT OFFICE INTERFACES WITH PRODUCT ASSURANCE
TEST INTERCONNECTION DEVICES

Training Report

RCA/Government Systems Division
Astro Electronics/Princeton, New Jersey

RCA

Course Title		Course Number
Starting Date	Length in Hours	Other

Name ______________________________ Occupation ______________
Last First Initial

Employee Number	Activity Number	Location
Supervisor		Supervisor Location
Organization (if other than AE)		
Original ☐	Recertification ☐	Special Certification ☐

School	Written Test Grade	
	Satisfactory	Unsatisfactory

Record of Demonstration

Workmanship Items	Satisfactory	Unsatisfactory
(A)		
(B)		
(C)		
(D)		
(E)		
(F)		
(G)		
(H)		
(I)		
(J)		

Comments (To Aid in Evaluating Trainee's Ability, List Trainee's Work Habits, Weak Points, Etc.)

Date of Completion	Typed Name and Signature of RCA Instructor	
[ ] Certified in	[ ] 60 Day Temporary Certification Expiring	[ ] Not Qualified for Certification

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Figure 1. Training Report

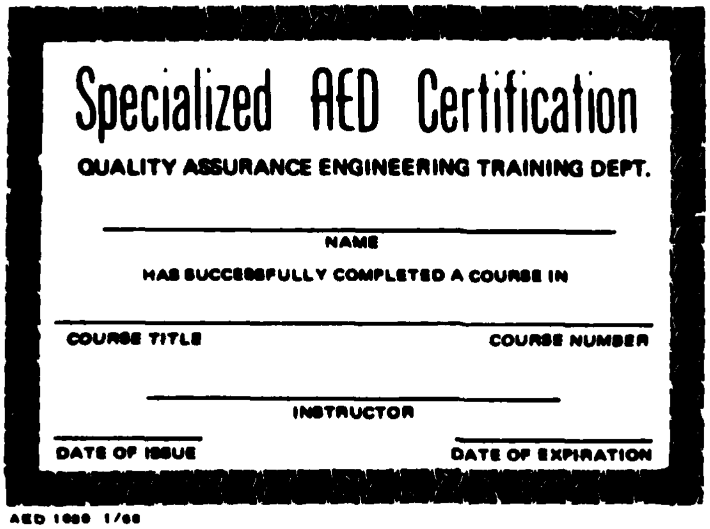


Figure 2. Certification Card

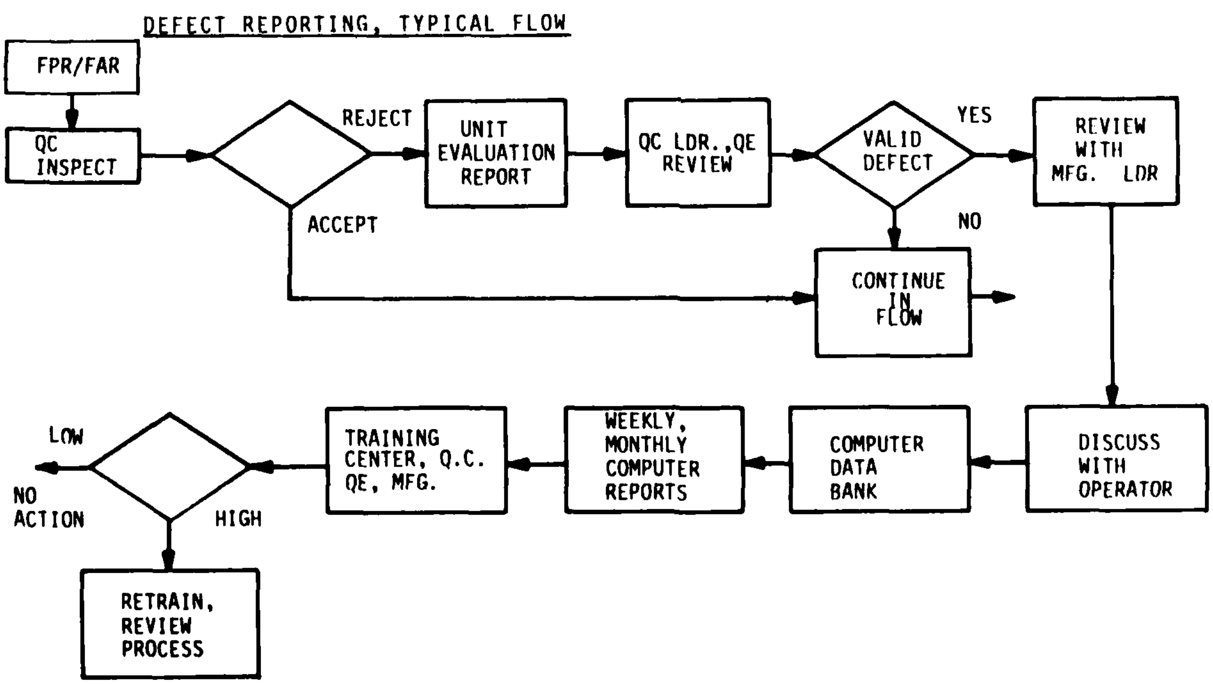


Figure 3. Defect Reporting System, Typical Flow

QUALITY CIRCLES AT HONEYWELL

By Dr. Michael Donovan

It's no secret that the United States is facing a real productivity crisis. The signs are everywhere, spiriling inflation, rising unemployment and lost markets to foreign competition. For over 10 years our nation has been on the bottom of the list of the world's industrialized nations in productivity growth. Organizations in all sectors of our economy are feeling the need to improve productivity.

Most organizations respond to the call to improve productivity by screw-tightening: increasing management control over things and people. But at Honeywell, Inc., the response has been exactly the opposite--and it's paying off. Instead of centralizing responsibility and strengthening controls to solve productivity pro' lems, Honeywell has been slowly decentralizing both the responsibility and authority for productivity improvement.

The central element in this decentralization has been the introduction of a Japanese invention known as Quality Circles. Quality Circles began in the 1960s as part of Japan's strategy to establish itself as a leading producer of high quality goods.

The Quality Circle concept is simple, but difficult. A circle is a small team of employees, who do similar or related work, who meet regularly to identify, analyze and solve work-related problems. Each circle is led by a supervisor or a senior employee who is specially trained in problem solving disciplines and group leadership skills. Simple. The difficult part is the making the Quality Circle process a way of life in an organization--where employees are provided with the opportunity, skills and leadership to participate in the management process.

Honeywell has been working for over six years to create an atmosphere in which Quality Circles can become a way of life--a method for managing people. The company was one of the first U.S. companies to adopt Quality Circles, starting its first circle in 1974. Since then, the program has grown to over 160 circles in seven major divisions of the corporation, making it one of the largest and most successful programs in the country.

Program Goals

Honeywell managers see Quality Circles as a key element in their strategy to improve both productivity and the quality of worklife. Their objectives are to:

1) Improve Productivity Through:

- Early identification of problems,
- Quicker and more knowledgable solutions developed at lower levels,
- Innovations in the methods of conducting the business,
- Greater distribution of responsibility for achieving results,

2) Improve Quality of Worklife Through:

- Greater involvement and participation of the workforce,
- Reinforcement of employee contributions through rapid response to ideas,
- Better communication and cooperation,
- Greater identity with a work team,
- Development of individual capabilities to solve problems and lead groups.

The program is based upon the belief that employees can creatively contribute to solving operational problems and that a truly participative role is reinforcing and will improve employee satisfaction.

Ingredients for Successful Implementation

There are several key principles that underlie a successful program. Figure 1. illustrates these principles.

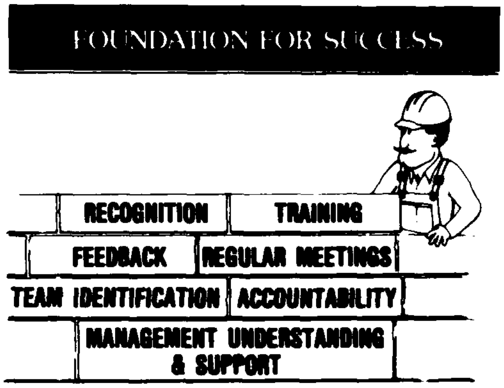


Figure 1.

Management Understanding and Support

For the program to be successful, management must see Quality Circles as a part of their strategy to achieve operational results. This requires a thorough orientation of managers, at all levels, to the Quality Circle philosophy and practice. In addition, management needs to play an active role in: planning the program; providing facilitation and coordination of circle activities; listening and insuring honest, rapid responses to circle recommendations; providing circles with information and feedback; and focusing the circles on important organizational goals.

This management role is usually carried out through a steering committee composed of key managers from the unit adopting circles. Sometimes this committee becomes a "second-level circle" to analyze and solve system-wide problems that go beyond the authority or capabilities of the operating circles.

Circle Identification

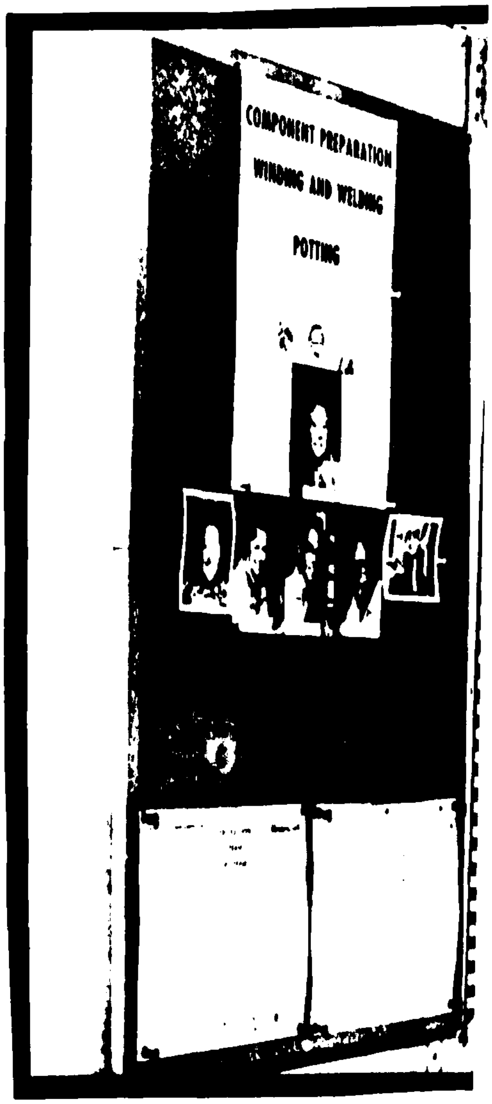
The process begins with a review of the existing work structure. The objective of this review is to identify circles where people, with common goals and problems, could benefit from disciplined efforts to solve those problems. In forming circles, consideration is given to factors such as similarity of skills, physical location, flow of work, connected functions and the existing structures.

Once circles are identified, leaders look for ways to highlight the circle's identity and build cohesion. Some circles have names such as: "The Circuit Board," "The Pacers" and "Payable Pencil Pushers." Other circles have designed tee-shirts, jacket emblems, name plates and team boards featuring [illegible] or photographs of circle members. Participation in a highly cohesive circle is more likely to be a source of satisfaction and pride to its members.

Accountability and Feedback

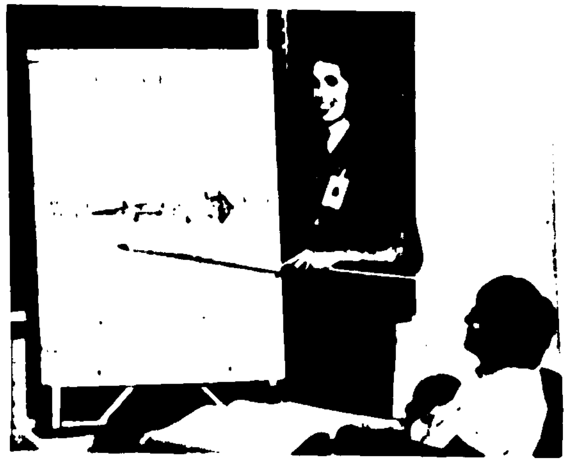
Once the circle is formed, members are encouraged to review their performance history. This might be in terms of cost per unit, defects per unit, or standard hours vs. actual hours or any other common measures of productivity. This is done to acquaint the circle with operating data and to help them select a goal or a theme. Circles are encouraged to set some specific measurable goals related to their own productivity and quality.

Once the goal or theme is established, the circle invents a method for collecting and tracking their performance data. This feedback is usually provided by means of large wall charts, placed directly in the work area. (Figure 2.)



Regular Problem Solving Meetings

The regular meetings are the means for achieving the goals established by the circle. Meetings are usually held every other week to review progress on action items and to identify, prioritize, analyze and solve problems. Quality circles use techniques like Force-Field Analysis; Pareto Analysis; Cause and Effect Analysis; and Brainstorming to identify and analyze problems. (Figure 3.)



The focus, however, is on inventing workable solutions and taking initiatives to implement those solutions. The "action register" is the tool the circle uses to manage the implementation of its ideas. It is merely a log that documents what is to be done, by who, and by when. It is reviewed and added to at each circle meeting. The action register provides a needed discipline and control and is an excellent communications tool with management.

Positive Recognition

As each circle makes progress, it is important to reinforce their efforts. Although participation and achievement of results are inherently rewarding, circle leaders are encouraged to use as many forms of recognition as possible. Management presentations, newspaper articles, internal conferences and awards have all been successfully used to reinforce circle efforts.

Training

The leader is crucial to the success of a circle. The circle leader, usually a first line supervisor, is responsible for planning the meetings, guiding the problem solving process, and setting the climate. Supervisors typically have little experience working with groups, particularly in a partici-

Training cont'd...

pative environment. Our training, therefore, seeks to provide not only skills but experience.

The training focuses on three skill areas: (1) the interpersonal skills of active listening and assertion; (2) planning and conducting an effective circle meeting, and (3) behavioral rehearsal of team meetings using the problem solving techniques.

The greatest time is spent in behavioral rehearsal, using video taped-critiqued feedback of mock team meetings. In small classes of 8 to 10, supervisors are prepared to orient, train and lead their circles in problem solving activities.

The training is conducted in a three-day workshop with follow-up consultation and coaching, on-the-job, by the program facilitator.

In addition, circle leaders are provided with a set of audio-visual modules that are used to train their teams in a variety of problem solving techniques such as brainstorming.

The Process

The first circle meeting is spent familiarizing the members with the Quality Circle concept and answering any questions. Next, the circle selects a goal or theme such as, "Reduce Unit Product Cost by 16% by Year End." The circle then identifies those problems that are keeping them from achieving their goal. Using the problem solving techniques, the circle members investigate and analyze the problems they selected. They request assistance from support organizations, such as engineering, when their investigations and ideas for solution are beyond the circle's scope. Once the circle arrives at a viable solution, they implement it, if it is within their authority, or present their recommendations to management.

Results

The results of Quality Circle efforts within Honeywell have been impressive:

Case 1 - *An electronics assembly department with 120 employees started 10 circles. Over a three year period, the circles solved over 230 operational problems and reduced the product costs by 36%.*

Case 2 - *Two high-volume, hybrid microelectronic production groups, with Quality Circles, were able to achieve 6% better learning curves than similar groups without circles. These improvements resulted in a 53% savings in labor costs on one program.*

Case 3 - *A heavy equipment machine shop, in a unionized plant, organized its 250 employees into 12 circles. Within the first year, the ideas implemented by the circles resulted in a 20% improvement in machine utilization.*

Case 4 - *A finance department started a circle in its accounts receivable department. Within the first six months, the methods improvements implemented by the circle resulted in a 13% increase in invoices processed per day.*

In case after case we have seen departments make dramatic improvements through the Quality Circle process.

The Avionics Division of Honeywell was the birthplace of the company's Quality Circle efforts. Today, the program continues to flourish there with over 80 circles in the manufacturing, finance, engineering, marketing, procurement and quality departments. In 1979, the direct labor and material cost savings produced by these circles exceeded $800 thousand dollars, a

6 to 1 savings to cost ratio.

At a recent Honeywell Quality Circle Conference, Clyde Molde, Vice-President of Operations for Honeywell's Defense Systems Division attributed savings in excess of $1 million dollars to the Quality Circle program in his Division. He went on to say that "the more significant outcome is the way our working style has changed as a result of the program."

Bill Van Horn, a Production Manager in that Division, best illustrated this change.

"When you sit down with your hourly people and really listen, you realize that they are as smart as you and have ideas as good as yours. It's scary at first, but when you get over the fear and learn to trust their contributions, you get freed up to do what you were hired to do - manage."

The hourly employees also see a number of benefits in the effort. Bob Cooper, a 30 year Honeywell veteran, who works in the Avionics Division in Minneapolis, compared the traditional and quality circle approaches to management.

"Before the foreman passed out what we were supposed to do and that was that. Now we meet in our circle and decide what we're going to do, what's the best way to do it and how we're going to do it. We're working together with our supervisor to make our jobs better and the company more productive."

QUALITY CIRCLES

Prepared by: R. Barra, Manager
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P.R.I.D.E. Productivity Prog.
Marine Division
Westinghouse Electric Corp.

Quality Circle/ noun A small group of workers, usually between four and ten people, who meet voluntarily, on company time, to identify the causes of on-the-job problems, and to propose solutions.

You've probably seen definitions like this one before. Simple ... succinct ... and incomplete. A Quality Circle is much more than a meeting of thoughtful workers. Look inside, and you'll find a carefully structured forum that encourages non-management employes to participate in the decisions that affect their jobs. Look a bit deeper, and you'll discover a powerful motivational technique that harnesses the creativity, intelligence, and experience of every Circle participant.

Today, there are about 120 Quality Circles throughout Westinghouse, including 50 in the Defense Group. By the end of 1980, there will be a few hundred. And by the end of the decade, several thousand. We've made our Circle program the major "people-oriented" component of our corporate productivity improvement program for five good reasons: Quality Circles can enrich the jobs of our employes, boost product quality, reduce manufacturing costs, raise productivity, and ultimately improve our operating profits.

Circular thinking

The traditional "top-down" school of management holds that problem-solving is a management function. In other words: workers should work and managers should think. By contrast, the "bottom-up" approach of Quality Circles spreads problem-solving throughout an organization. Management ultimately makes the decisions, but employes take part in the search for ways to improve their on-the-job performance.

For example, a Quality Circle at the Baltimore Defense Electronics Division concluded that productivity would go up if current specifications and drawing requirements were summarized on a wall chart visible to everyone in the work area. Another Circle proposed that one employe arrive two-hours before a shift change to warm up processing equipment for four other people. The time savings: two man-hours per shift. A Third Circle recommended a new method of applying adhesive to printed circuit boards that cut defects two hundred fold.

The idea behind the ideas

Quality Circles are based on the premise that the people who do a job everyday know more about it than anyone else. They are in the best position to think through a problem and come up with a workable solution ... particularly when productivity is involved.

When employes are asked what to do, instead of being told what to do, they respond to the challenge with more than good ideas. Morale goes up, and with it the team spirit that motivates employes to be more productive. Employes take pride in their work. They develop a personal stake in productivity, product quality, and reliability. They welcome advanced technology because they feel "in charge" of it. There is less resistance to change because employes help to initiate it. Communications between management and employes improves dramatically, and employes come to understand the role they play in their organization. These intangible benefits will often outweigh the value of the ideas themselves.

What a Circle is:

Let's add a few specifics to the definition at the top of the previous page.

- The members of a Quality Circle are co-workers in one section. Participation is purely voluntary; workers are invited -- never compelled -- to form a Circle. Workers who choose not to join are told what the group is doing, and they are given frequent opportunities to participate in supporting activities.

- A Circle usually meets one hour each week, ideally away from the workplace in a meeting room set aside for the purpose.

- Every Circle has a leader -- usually the section's first-line supervisor. His or her job is to keep the meetings on track, help resolve disputes, and guide the Circle to appropriate problems. Leaders are trained to chair the meetings in a way that promotes the free exchange of ideas.

- Circle leaders go through a preliminary

three-day training program taught by a Quality Circle facilitator. This is a management-level employe who is the formal link between the Circles and Division management. He or she assists the Circles in their activities; provides the information, materials, and other resources they need; and helps them develop their presentations to management. As a rule, a facilitator with two or three years of experience can comfortably oversee 10 to 20 Circles.

- The facilitator attends -- and helps to lead -- the early meetings of a newly formed Circle. This gives the leader an opportunity to gain experience.

- Members are taught a variety of fundamental problem-solving techniques during the first six or eight Circle meetings. For example: data gathering and graphing, brainstorming, cause-and-effect analysis, and Pareto analysis. And they also learn how to present their conclusions and recommendations to management.

- A Circle will spend four to six weeks analyzing a typical workplace problem ... although an experienced Circle may spend several months solving a highly complex problem. Then the facilitator arranges a meeting with the appropriate level of management, so the Circle can present its proposals.

"Management can accept, reject, or modify a Circle's recommendations," explains Ralph J. Barra, Manager of Corporate Product Integrity, and coordinator of our corporate Quality Circle program. "The Circle proposes solutions; it does not implement them. In effect, a Quality Circle multiplies the intellectual resources available within a division without diluting any of management's authority or prerogatives."

Barra's group -- located at the (W) R&D Center -- has become the in-house Quality Circle consulting team. It provides start-up advice and materials; trains new facilitators; and keeps track of the fast-growing program for the Corporate Productivity Improvement Committee. Barra is an enthusiastic advocate of Quality Circles --- and a storehouse of information for program planners.

Guiding the Circle

"Structure and direction are essential," says Barra. "A Quality Circle is not an ad hoc management advisory committee or a gripe session. The facilitator and leader are the rudders that steer the Circle towards job-related problems that its members have the expertise to solve. Personnel and industrial relations problems are off limits. So are discussions about the performance -- or lack of performance -- of specific individuals."

A new Circle will focus on simple workplace problems that offer a high probability of success. Early achievements build confidence and experience. Then the Circle can tackle more ambitious projects that may involve the cooperation of other sections and other Circles.

"In time," says Barra, "the group will shift gears from problem-solving to problem-preventing. All the while, the members are learning about their jobs, their section, and their division. They are experiencing personal growth and development. And they are learning to communicate with each other, their supervisor, and their management.

"This evolutionary process generates the long-term benefits of the Circle program. But it can't happen unless senior division management accepts three broad responsibilites:

"First, management must welcome employe participation. This means listening to the ideas offered by Quality Circles ... implementing as many of the good ones as possible ... and explaining why rejected proposals can't be implemented.

"Second, management must provide the infrastructure to support the Circle program. Capable facilitators, meeting rooms, and training materials are only the starting point. Management must encourage organizations throughout the division to cooperate with every Quality Circle. No Circle operates in a vacuum. Solving a problem in Section A will often impact the activities of Section Z. Practically speaking, this demands the commitment of the plant manager. Without it, the program won't last long.

"Third, management must create a system for recognizing the achievements of its Quality Circles. Self-respect and self-esteem are the engines that power the program. Recognition is the fuel. There are many ways to show support and applaud performance.

For example, senior-management luncheons with Circles; mementos such as "T" shirts and wall plaques; articles in plant newspapers; yearly award banquets; and -- taking an idea from Japan -- trips to see Quality Circles at work in other companies and other countries."

A few financial details

It's impossible to calculate the return on investment for a Quality Circle program because there are so many intangible payoffs that don't carry a price tag. Some ROI estimates at other companies (based solely on cost savings yielded by improved productivity) exceed 500 percent. However, total total costs are low. The major costs of a start-up program are: The facilitator's salary and benefits; employe expense associated with members meeting one hour a week on company time; and travel expense and training fee for the facilitator. A starter kit of training materials for five circles is provided free, thanks to funding from the Corporate Productivity Improvement Committee.

White-collar Circles

"The next step in our program," says Barra, "is to expand the Quality Circle concept to professional and support employes. White-collar Circles have a less formal structure. They can meet less often than once a week, each meeting can last longer than an hour, and members may work in different sections ... although they will have similar job responsibilities. Problem-solving tends to focus on challenges that are generic to a profession or support function. For example, speeding the production of engineering drawings, or reducing the time to prepare typed letters. The emphasis is on providing the tools professionals and support personnel need to do their jobs better."

Quality Circles

The first Quality Circles (see Made In Japan on page 16) worked to improve product quality. "But we think oru Circle program," says Barra, "will do much more. We want to improve the quality of our processes, the quality of our systems, the quality of our information resources, the quality of our employes, the quality of our management, and ultimately, the quality of our company."

Made In Japan

For half of the 20th Centrury, a "Made in Japan" label was a warning to consumers. And then, Japanese industry invented the Quality Circle.

The story begins back in the '50s, when two American consultants brought Western quality-control techniques to Japan. They taught the need for company-wide programs to raise quality, and they stressed that an entire work force must be involved ... not just a few designated quality-control managers.

The Union of Japanese Scientists and Engineers agreed. They prepared an easy-to-understand handbook on quality for production supervisors. But few people read the text on their own. And so the Union came up with the idea of "reading circles": groups of supervisors who met to discuss the book and talk about quality. Supervisors liked the idea; they formed reading circles with their own workers. The meetings grew into problem-solving sessions, and the Quality Circle was born.

By one estimate, there are a million Quality Circles in Japan today, involving about ten million workers. But product quality is only one of their concerns. Japan imports most of its raw materials and energy; reducing waste and conserving energy have long been national priorities. Quality Circles attacked these problems in the late '60s. Many of the solutions they proposed increased productivity. By the mid '70s, the tail wagged the dog: Millions of Japanese workers were thinking together to give Japan the fastest-growing industrial productivity in the world.

Tom Murrin, President of Public Systems Company(W) and Chairman of our Corporate Productivity Improvement Committee, sums up the potential of Quality Circles with this anecdote: "A few months ago, I asked a leading Japanese expert on productivity a simple question: If Westinghouse could implement only one program to improve productivity, what would you recommend? He answered without hesitation: 'Put in a Quality Circles program.'"

QUALITY/PRODUCTIVITY MOTIVATION AT MARTIN MARIETTA MICHOUD ASSEMBLY FACILITY

BY

ROBERT LOZANO, MA

A worrisome trend has recently become apparent in the industrial posture of the United States. Our productivity has taken an uncomfortable decline from its annual average growth rate of just over 3% through the sixties (Time, August 27, 1979: 36) to .4% in 1978 (Ibid.). This performance has given the United States the lowest productivity growth of all major industrial nations (Wall Street Journal, 21 Feb. 1980). Concern has also been raised over our decline as a leader in the manufacture of quality goods (Bhote 1979: 795).

These declines in productivity and quality appear to be inextricably related. Poor quality products have to be remade; hence productivity is correspondingly reduced. A third important component that warrents our attention is safety, since it has an overlapping influence on both quality and productivity. It has been our experience that any motivation efforts are easily erroded and neutralized when the shop operator feels that he or she is working in an unsafe environment. No number of awards can alleviate the anxiety of a flash fire or reduce the discomfort of an irritating chemical agent. The effect of a safety incident is further compounded when one considers the down-time that might be experienced due to a damaged facility, personal injuries, unsalvageable products and tie-up of the appropriate support personnel.

The problems of maintaining a good motivation effort that results in quality cost-effective products come into sharp focus when we deal with man-rated space flight hardware. Quality and safety become paramount. We would expect that having the unique opportunity of working with this type of hardware would provide the incentive to maintain a high degree of personal motivation. After all, how many opportunities are available where a person can actually have a hand in shaping the future?

We cannot categorically dismiss the absence of such motivation. It does exist, but usually in areas that have experienced a history of aviation and aerospace development, such as the Los Angeles Basin. At our aerospace operations at the Michoud Assembly Facility in New Orleans, we could initially draw from a pool of former Boeing and Chrysler employees experienced from the Apollo program. This source of experienced personnel was soon exhausted and we had to draw from the available labor market.

The New Orleans area, and indeed southern Louisiana, has experienced a long history of agrarian and agricultural products processing activities. The area's two large industrial bases, i.e., shipbuilding and the petroleum/petrochemical industries, have only been developed since 1951. From these two sources we have drawn approximately 35% of our floor personnel. The remaining 65% of the work force has had very little industrial experience, even less aerospace related experience or no experience at all. It is against this background of circumstances that we frame our motivation effort.

Our effort at Martin Marietta Michoud is founded on a four-faceted approach. A Manned Flight Awareness program, a Supervisor Development Training program, a Performance Award plan and an employee participation undertaking.

Manned Flight Awareness

Because we are primarily an assembly facility, a very large percentage of our products are manufactured "out of house." These products range from basic fastener hardware to primary subassembly components. This situation has prompted the necessity of an effective and vigorous supplier-oriented and in-house Manned Flight Awareness program.

o Supplier Visits

Our current supplier-directed effort consists of providing a Manned Flight Awareness presentation to thirty-eight major External Tank (ET) suppliers

located throughout the United States. The presentation consists of a comprehensive slide program that details the major Space Shuttle components, i.e., the Orbitor, the Solid Rocket Boosters (SRB's) and of course our product, the External Tank. This is followed by a profile of a typical mission from launch to earth orbit.

During the viewing of the mission profile we highlight that moment during the mission when the supplier's product is performing its function. We underline the criticalness of that particular component, and point out how its performance relates to the success of the mission. At this time a vast majority of the supplier's personnel realize, for the first time, what their product does and see the results of their efforts. Furthermore, these same people realize for the first time what can happen if their product fails. After the slide presentation we display a 1/100th scale model of the Space Shuttle and conduct a question-and-answer session. This is followed by a motion picture of the Approach and Landing Tests.

We conclude our presentation by giving each employee working on the product a pack containing literature and information on the Shuttle, an External Tank decal, a 'first flight patch' decal and a letter from our vice-president and general manager emphasizing the importance of everyone's efforts to insure mission success.

o Supplier Posters

Very recently we have added a new feature to our supplier visits to reinforce the awareness that we want to stress in our presentations. We call this feature a supplier poster. The poster layout is dominated by individual photos of all the Shuttle astronauts across the top and bottom thirds. In the center is a line drawing of the External Tank with a circular highlight designating where the supplier's product is located on the tank. Alongside this display is a close up photo of the product on the ET.

o Results

Response to our supplier visits has been very good, indeed excellent. We have had numerous requests for additional presentations, and we are incorporating them in our schedule as time permits. In case after case we fulfilled a need for basic information and public awareness of the Shuttle program, in addition to raising the level of product- and job-related manned flight awareness.

It gives us a great sense of satisfaction to know that people working on our products now realize that the Shuttle will be launched from Pad 39A at KSC instead of "off the big jet." Perhaps this is indicative of an information gap that needs to be bridged, if we seek public support for our space programs.

o In-House Programs

Our product education efforts at Michoud stem mainly from our response to accommodate a large labor force with little or no experience in the aerospace sector of industry. This condition is expected to remain the same over an extended period (Times Picayune, 13 April 1980). Because of this circumstance, we have to direct our efforts to our employees as soon as they walk through the door.

Our present posture includes a New Employee Manned Flight Awareness Orientation, Manned Flight Awareness weekly lunchtime movies, ET roll-outs, astronaut visits and in a more general motivation vein, a yearly family day picnic.

Supervisor Development Training

The lack of skilled personnel also impacts our supervisory ranks at both the first and second level. Attrition factors such as retirement and changes of professions have obliterated the supervisory personnel that were present in the area at the height of the Apollo-Saturn program. Some are left, but they are insignificantly few in number. This situation has literally forced us to build almost all of our first and second level supervisory tiers in Quality and Manufacturing. The available supervisor candidates are usually people from the hourly ranks that have had some time on the floor. For the most part this leaves us with a lot of young supervisors in their twenties supervising their equally young peers. These

circumstances have produced some problems in attaining a disciplined operation and in developing a good ambience of safety consciousness.

Initial responses to this situation include personal training sessions conducted by some of our Quality Chiefs. On a once-a-week basis, seminars were held to cover the basic aspects of inspection techniques and methodology. The necessity to provide such basic training reflects, in part, a need for educational opportunities in the public sector such as those which are available, for example, in some of the Community College districts (Courses, 1979 - 1980: p.100) of California.

Our present efforts consist of a comprehensive thirteen course Supervisor Development Seminar and weekly supervisor luncheon meetings. The training program is the keystone to our overall development endeavor. It is administered by our Training Department which processes approximately twenty supervisors every four weeks. The courses include sessions in motivation, covering the theory and its applications; and Systems Refinement Teams, which is an introduction to Quality Circles.

The weekly supervisor luncheon meetings are designed to promote a sense of involvement and interdepartmental fraternity among the supervisors. Typically the meetings consist of a briefing by a department manager and his staff, detailing that particular department's function and current activities. After the briefing, everyone convenes in the Executive dining room for an informal luncheon.

These meetings have elevated morale and imbued the supervisors with 'Team spirit' because upper management has involved them in something more than just the routine expectations. The results have matched our original goal.

Performance Awards

After our personnel are 'on board,' they become eligible for any one of the three categories of job performance and special achievement awards.

o Spot Awards

Recognition is given, at the prerogative of the person's supervisor, for excellence that is deemed to be outside the scope of required work. Awards given for this recognition consist of Shuttle plaques, pen sets, bronze medallions (depicting the External Tank) and sports event tickets.

o Sustained Performance Awards

When an employee demonstrates an outstanding work performance record for a period of at least three months, his effort is recognized by our sustained performance award. The award is a sterling silver medallion depicting the External Tank and is usually presented by someone at the managerial or directorial level.

o Special Achievement Awards

Supervisors of both hourly and salaried personnel can cite their outstanding people who have a record of exemplary performance by nominating them for candidacy for Employee of the Month (EOM). Final selection is made by members of the Manned Flight Awareness Committee, the directors and our vice-president and general manager. This award carries with it a plaque, a cash prize, reserved parking and eligibility for employee of the Year.

The same Manned Flight Awareness Committee convenes to select the Employee of the Year. The candidates are the past Employees of the Month. This award carries the same perquisites as the EOM, except that the cash prize is doubled and the winner and his family are Launch Honoree participants.

Ranking high in prestige is the Snoopy Award. In conjunction with our astronaut visits, this award is presented to the people who have been chosen by the Manned Flight Awareness Committee for exemplifying the standards that reflect mission success.

Employee Participation

We presently promote two principal areas of activity to provide direct participation in people benefiting activities by any employee on a voluntary basis. These activities are designed to encourage participation at a decision-making level and consist of the Employee Suggestion System and Systems Refinement Team. The latter is our own particular brand of Quality

Circles.

o Suggestion System

We have recently completed a thorough study and assessment of our suggestion system. The outcome of this study resulted in a major overhaul and updating of the existing plan. Our aim is to provide a more smoothly functioning system with a more equitable payback, which will encourage greater participation. Current data indicate that in 1979 18% of the employee population participated in the old system. Of this total 73% was from the Manufacturing sector. Data gathered in 1980 will be compared to this baseline and will indicate the effectiveness of our improvements.

o System Refinement Teams - Quality Circle

Our most intense employee participation activity thus far has been our Quality Circles (Juran, 1976), which we refer to as Systems Refinement Teams or simply SR Teams.

The functional structure of some of our teams appears to be unique among Quality Circles and is discussed in detail in recent papers (Lozano and Thompson: In Press), (Thompson: 1980). Basically, it consists of a core - support operator concept, in which the 'hands-on' operators form the core of the team and work in conjunction with representatives (support operators) from those departments that interface with them on a day-to-day basis. In this manner many of the barriers that inhibit communication among the different departments are surmounted. It has been our experience that in many problem cases, the primary casual factors were these barriers (Ibid: 2).

The unique aspect of our team structure is the fact that we have extended this concept to overcome intercompany barriers. This development evolved after we discovered that we were receiving more than 90% of the components for a major assembly from a single source, AVCO Aerostructures in Nashville. Our project manager suggested the concept of forming a corresponding SR Team at AVCO in order to attack existing problems from both ends of the line.

We transformed this suggestion into a very successful reality. Approximately three weeks after the teams held their first joint meeting via a teleconference hookup they resolved a number of significant problems that had existed for years. On April 18, 1980, these two teams made a joint presentation at our facility, where they demonstrated a savings of at least 365 manhours per assembly.

Conclusions

As with any motivational endeavor, it becomes desirable to produce some type of quantifiable data that allow us to measure the degree of success or failure of our efforts. As our multifaceted motivational program is gaining maturity, we are assessing the results in various ways.

Initially results of our Manned Flight Awareness program at the suppliers were measured by the complimentary response we received from the people in attendance and by letters of commendation. At present we are taking a more objective approach by tracking the types and frequency of nonconformancies as they occur in the periods before and after our presentations. Data of this type will be forthcoming.

Our in-house MFA program is producing the desired results. The first line supervisors are achieving a sense of importance and worth with their training. This is instilling self confidence in them which manifests itself in better discipline. Many of these gains are intangible and therefore difficult to 'measure.' However, attitudinal changes in some people have been significant enough to be apparent.

The awards program has just been measured with a survey that sampled 30% of the employee population. The response indicates that 70% of the employees feel that the program is adequate and accomplishing its intent. This majority also feels that the number of awards presented (in all categories) is not excessive.

Becasue we are in the process of implementing an upgraded suggestion system, we have not yet acquired data to provide a comparison with the previous system. Once these data are available, the proposed comparison will reveal the effectiveness of that effort.

Results from our SR Team activities have been both tangible and intangible. We have had three management presentations from the first group of ten teams which have been active for approximately seven months. The solutions to the problems that were worked are expected to save hundreds of man hours per tank in the manufacturing sector and an equal number in the support sector.

At AVCO Aerostructures there was an 83% drop in defects on Shuttle-related components. This represents a decrease of hundreds of nonconformities per assembly and reflects the change in attitude that developed after the vast majority of the workers on that product line participated in SR Team activities.

On the intangible side, we have seen a perceptible change in the attitude of the SR Team members that reflects a sense of participation at the decision-making level. The teams strive to achieve more productive utilization of time and work toward the prompt resolution of safety problems. In their reserach of problems they have gained an appreciation and awareness of managerial duties that was not there before. Indeed, we have seen complete reversals in the attitudes of acknowledged 'trouble-makers.'

The progress of SR Teams is one area that we are prepared to measure in depth. In addition to counting the tangible gains, we are administering an attitude survey that has been specifically designed for Quality Circles. This survey follows a general format so that data can be compared among different companies. We expect this data to be extremely useful.

In general, we are pleased with our overall approach to Quality and Productivity motivation. We believe that we have some sound and dynamic programs that are well-accepted and are showing some very encouraging results. As our measurement effort matures, we feel that the quantifiable data will justify our present enthusiasm.

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AN EXAMPLE OF THE COMMUNICATIONS NETWORK FOR A MAJOR LAUNCH VEHICLE PROGRAM

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Introduction

Experience sharing has been used in many contexts. The term can be roughly defined as the communicating of knowledge, skill, or practical wisdom derived from observation of or participation in events. Generally, it is referred to and interpreted as "information exchange." In a more general sense, it can be defined as a "communication network" or merely "communications." This paper presents the communications network or the experience sharing network as employed on the Delta launch vehicle program.

Background

The Delta launch vehicle program was established as an interim launch vehicle program in 1959. During the intervening two decades, 151 missions were launched with 139 being successes resulting in an overall success rate of 92 percent. This was achieved with an everchanging vehicle configuration being upgraded to accommodate major increases in payload capability requirements. Through the first 102 Delta launches in the growing years of the agency, the 90 percent success record was notably acceptable and was achieved at a moderate cost. However, as the payloads became less replaceable and more expensive, the obvious conclusion was reached--strive for 100 percent mission success for space launch vehicles. This modification to program direction was effected on the Delta Project in 1974. For the past 49 launches within this new period, the success rate for Delta has been 96 percent, an increase of 6 percent with only one spacecraft loss. This higher mission success rate has been the direct result of major program and organization changes implemented to comply with the revised goal of mission success approaching 100 percent. These changes included new technical and management systems, reviews and procedures along with staff augmentation for the government, prime contractor, associate contractors and subcontractors. The experience sharing or communications network utilized to accomplish the contemporary Delta is treated herein.

Network Approach

In revising the program to accomplish the redefined 100 percent Mission Success Goal, a total systems approach to the overall management of the program was employed. The program and organization were modified to include additional reviews, procedures and surveillance to the point of redundancy, where necessary. The significance of the tenet concerning "good people talking a lot" was recognized and a greatly increased informal communications activity was established. A central element identified for substantial augmentation was the role of the cognizant-engineer. The staffs were also augmented in both the industry and government sectors and interfaces between government and industry were increased to establish very close working relationships. In order to retain the greatest flexibility while striving for maximum assurance of program and launch success, keeping in close touch became the maxim for all levels. Organizations internal to government and industry were modified to insure that all project members were motivated to participate and be responsible from Vice President/Senior Management down to on-line operations personnel. The primary goal was 100 percent mission success and included was the adaptation of a communications network both on a formal and informal basis.

Although cognizant engineers had previously had a program role, their responsibility was increased extensively as were the total numbers. These individuals are assigned certain components, systems or subsystems, and "live" with them through all aspects of the program including design, procurement, production, checkout, launch preparation,

launch and post-launch activities. The cognizant-engineers are identified and assigned responsibility in both the government and contractors' sectors and function as a team and complement one another.

For the contemporary Delta the role of the Delta Launch Vehicle Engineer (DLVE) was introduced into the organization. The DLVE is assigned a launch vehicle early in the production phase and follows the vehicle through production, check-out, launch preparation, launch and post-launch activities. He essentially serves as a systems cognizant-engineer. The duties/responsibilities of the cognizant-engineer in the complete cycle are as follows:

- o Assures Flight Integrity of Critical Components
- o Maintains Complete Data File for Each Component Including Trend Analysis
- o Develops and Maintains Chronology and File of Rejection History Including Failure Analysis Results and Corrective Actions
- o Informs Supplier of Delta Flight Performance
- o Periodically Visits Manufacturing and Test Areas (In-House/Suppliers)
- o Reviews FAB, Assembly and Test Data
- o Approves Drawing/Process Changes
- o Conducts Failure Investigations, Performs Failure Analysis, Provides Failure Documentation and Determines Change Actions
- o Supports Program Readiness Reviews
- o Provides Statement of Launch Readiness for Each Assigned Component by Serial Number Prior to Every Launch

Figure 1 depicts how various elements focus toward launch success motivation and specifically how the cognizant-engineer is the central focal point.

These elements are not organizational elements but rather functions which are included in all organizations. For example, Program Management is made up of the project manager, program office, engineering, quality assurance, and manufacturing. All organizations have a responsibility, are included in the process and are motivated toward the single objective of launch success.

Network Elements

The major communications system elements that are utilized by the cognizant-engineer and the entire project team can be categorized into the following:

1. Change Management System
2. Quality Assurance System
3. Nonconformance Quality Assurance System
4. Other Program Assurance Systems
5. Informal/Verbal Communications

These elements are not separate or independent from each other but are highly interactive.

1. Change Management System

   The Change or Configuration Management System utilized by the prime vehicle contractor on the Delta Program is illustrated in Figure 2. This system includes participation from all organization and personnel levels within the contractor's project organization. Additionally covered are the interfaces between the government and the contractor and also between the headquarters and field organizations of the government. The project is managed by the field organization in concert with the headquarters program office which interfaces with the vehicle users for definition of requirements.

   The approval and review process of a change order is shown in Figure 2. The change authority can be initiated by the government or the contractor; however, somewhere in the cycle, the

government must authorize it with a "work authority." The mechanism for the proposed change is an Engineering Change Proposal, (ECP). Tracing the route of the ECP illustrates the overall communications network elements utilized. These include reviews at all levels such as Senior Review Board and Design Reviews. There are different levels of management review/approval depending on the type of change and the cost involved. The vehicle user (spacecraft customer) gets involved in the approval/review process for mission peculiar changes which might affect or influence his hardware.

Figure 2 deals with the prime contractor's system; however, the systems for the associate contractors are similar.

2. Quality Assurance System

The Quality Assurance System employed by the prime contractor is shown in Figure 3. The figure shows the communication network that is used in the program for both hardware and software requirements. This is the normal or conformance assurance system and depicts the documentation involved, the levels of review, and the involvement of engineering, quality, production, management, operations and customer interfaces in the overall process. One can readily see the detail, level, and redundancy involved in the system and all involved share in the responsibility.

As indicated before, there are similar networks for the associate contractors.

3. Nonconformance Quality Assurance System

The Nonconformance System provides the following key features for failure resolution:

- o Design and Reliability Participation in Failure Investigation and Resolution
- o Parts Specialists Perform Failure Analysis
- o Reliability and Program Management Approve Analysis/Investigation and Corrective Action
- o Safety Evaluations of Nonconformance Reports
- o Computerized Data Storage/Reporting
- o Failure Trend Evaluation as the First Step in Failure Investigation/Analysis
- o Reliability Verification of Corrective Action
- o System is Closed Loop

Figure 4 presents the communication network flow chart which is utilized when there is nonconformance in a system, subsystem, or component. This nonconformity could be for any reason; i.e., out of specification, operational problem and so forth. The various organizations such as quality, engineering and production are involved. The process is initiated by an MRR, which is defined as Material Record Review. The level of management review depends on the problem and can include senior contractor, government and user personnel.

4. Other Program Assurance Systems

This category includes:

a. Preship Reviews

b. Walk Arounds

c. Special Readiness Reviews

d. T-3 Day Flight Readiness Reviews

e. Classic Reliability Functions

f. Master Line Checks

g. Post Launch Flight Data Reviews

All of these systems have been part of the Delta Project since program inception. However, for the contemporary Delta many of them were modified significantly. For brevity, only the more significant systems will be discussed herein.

The Preship Review is new with this era replacing the T-30 day flight review. The review is now conducted as it is named before the vehicle is shipped to the field for launch processing and readiness. The decision to ship is made at the conclusion of the review. The review is conducted at the senior management/specialist level of the joint government/contractor(s)/user team. The specific areas covered are:

- Mission Description
  - Spacecraft Description
  - Mission Requirements
  - Vehicle Configuration
- Mission Peculiar Analysis
  - Flight Mechanics
  - Structural Loads and Margins
  - Battery Margin Analysis
- Vehicle Checkout History
- Launch Site Status
- Subcontractor Status
- Associate Contractor Status

The T-3 Day Flight Readiness Review has always been an important part of the program. However, for the contemporary Delta, it was extended and made more exhaustive with a comprehensive update of all the items covered in the Preship Review. The review team is made up of senior management/specialist personnel from the various sectors and, in most cases, includes a larger complement of specialists than the Preship Review. The decision at the conclusion of the review is the "go-no-go" for fueling the vehicle for launch. All open items and discrepancies including open documentation items must be dispositioned and closed out prior to launch "go-ahead." The major items covered at this review are:

- Mission Checkout Status
  - Significant Component Rejection History Update
  - Failure Analysis Review Update
  - Nonreproducible Anomaly Update
  - Anomaly Report Update
  - Alert Impact Update
- Launch Checkout Status
  - Field Station Checkout History
  - Field Station Problem Review
  - Events to Liftoff
- Range Status
  - Data Acquisition
  - Range Safety
  - Weather
- Subcontractor Status
- Associate Contractor Status

Another important aspect of the overall communications network or experience sharing are the activities covered during the Post-Launch Flight Data Review:

- Technologies Review All Available Flight Data
- Flight Data Critique Meeting
  - Technologies Summarize Results of Flight Data Review
  - Identify Anomalous Vehicle Systems Performance in Final

Countdown Minutes or Actual Flight

- o Establish Anomaly Report Assignments as Required
- o Present Summary of Flight Data Critique Meeting in Memorandum Form Management
- o Close-Out Anomaly Reports Commensurate with Future Mission Applicability

5. Informal/Verbal Communications

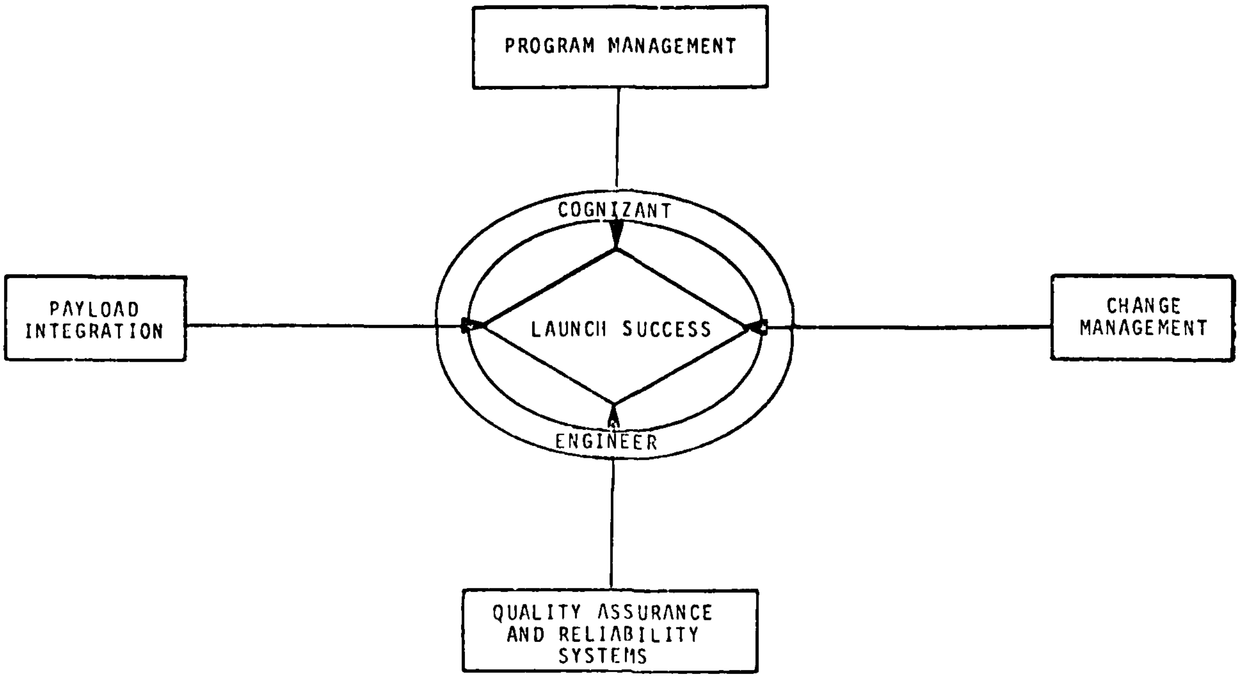
With the augmentation of the staffs for the government and industry teams, the joint management team issued direction to personnel encouraging more informal or verbal communications. For the contemporary Delta to achieve its mission success goal of 100%, it was recognized that peer groups and counterparts had to be in constant communications, via telecon, meetings and the like. Since the prime government and industry teams are a continent apart, this is of utmost importance.

The results have proved most favorable. The amount of time spent on the telephone has increased significantly and so has the time devoted to informal meetings and reviews. Personal relationships between government and industry counterparts have matured into mutual respect, trust and excellent rapport. The intangible, positive results are noteworthy. Certainly, these informal communications have not replaced the formal correspondence requirements which are necessary and important; but, the program has benefited considerably.

Conclusions

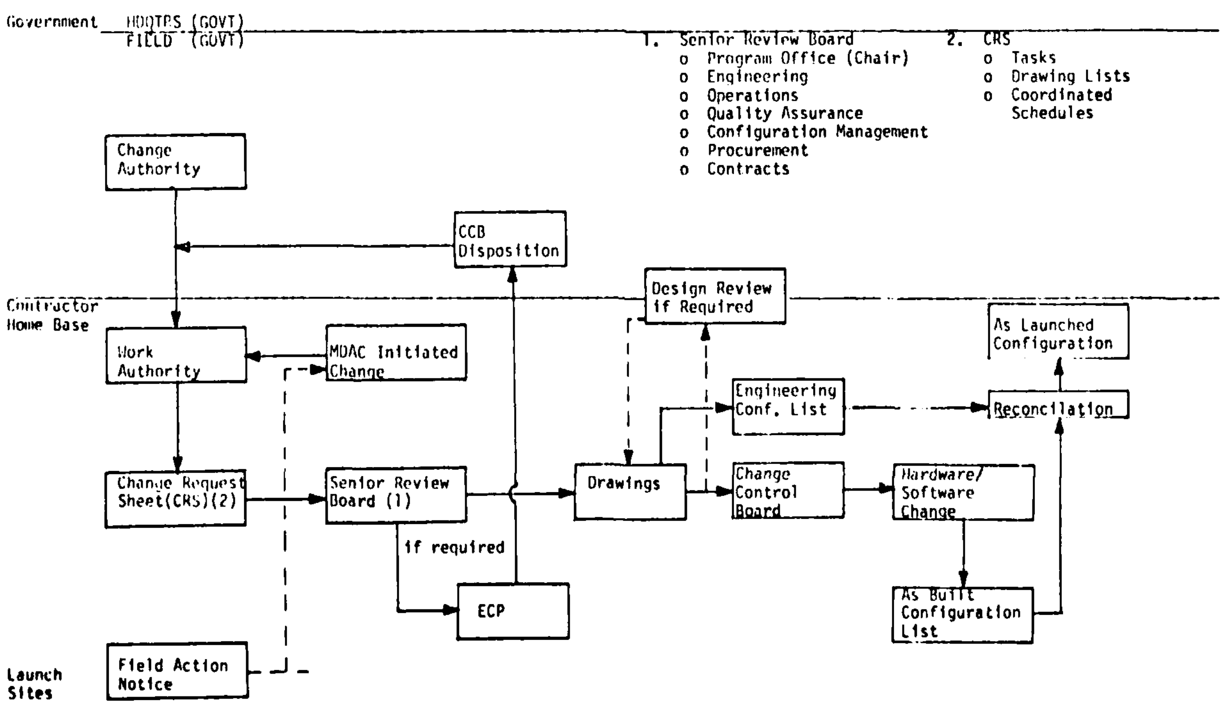
The network as described and applied to the Delta Launch Vehicle Program for communicating and sharing work experience has had positive measurable results. The establishment of the Delta Launch Engineer and the amplified role of the cognizant-engineer were the two major mechanisms used to enhance the communication network of the Delta Program. This enhancement coupled with indepth reviews, formal and informal communications, and efficient organization changes have played a significant role in increasing the Delta launch success rate from 90 percent to 96 percent.

DELTA PROGRAM

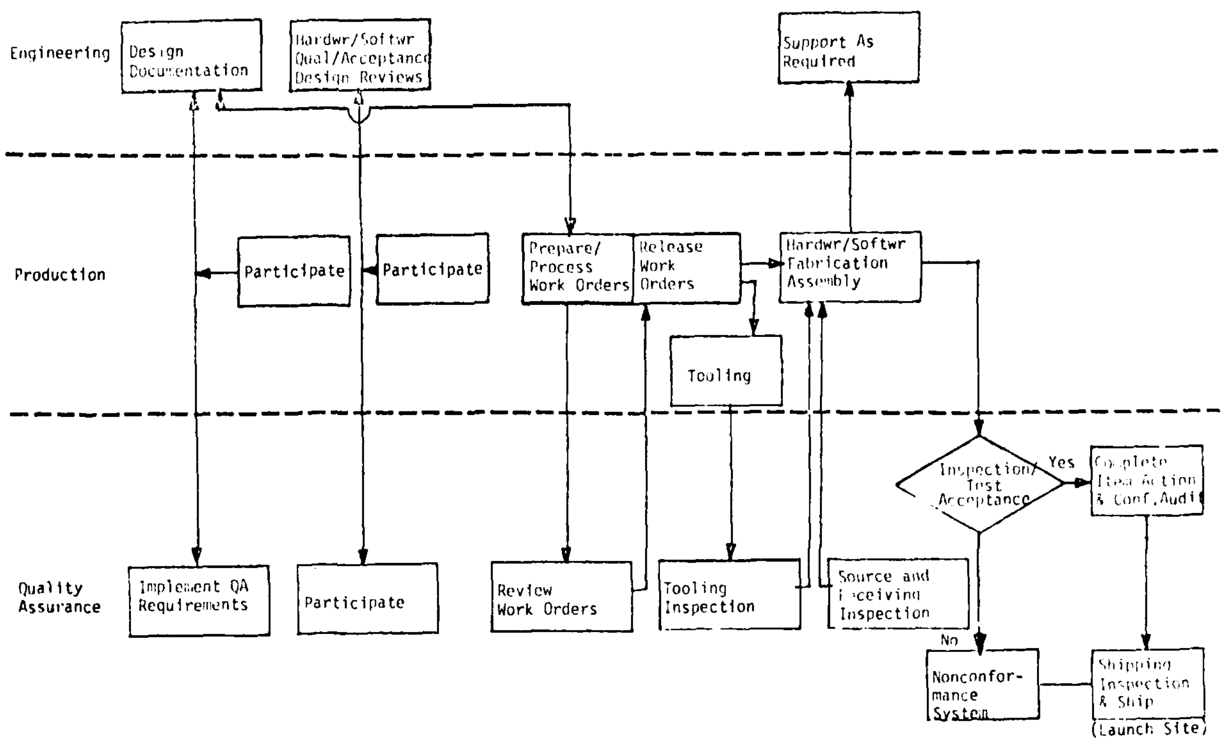


CHANGE MANAGEMENT

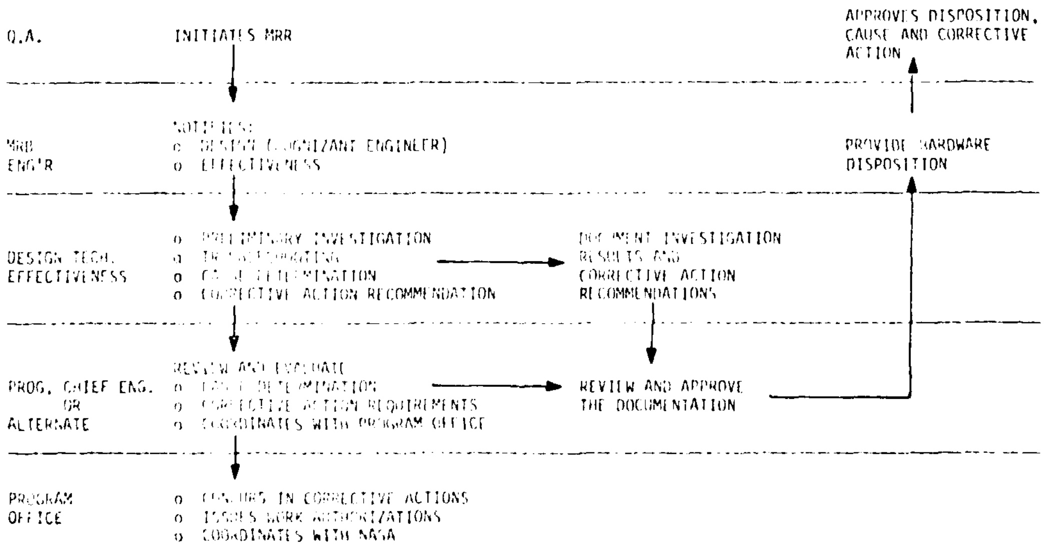
(Production and Mission Peculiar Changes)



QUALITY ASSURANCE SYSTEM



QUALITY ASSURANCE NONCONFORMANCE SYSTEM FAILURE INVESTIGATION AND CORRECTIVE ACTION FLOW DIAGRAM



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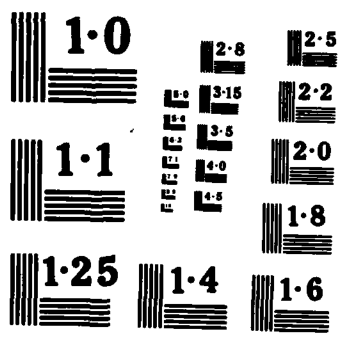
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SUMMARY OF ISSUES AND RECOMMENDATIONS

MOTIVATION, TRAINING AND EXPERIENCE SHARING

SUMMARY OF ISSUES AND RECOMMENDATIONS

1. Top Management Commitment

Issue

Top management in most organizations lack a firm commitment to quality.

Recommendations

- Government and industry associations should emphasize management responsibility to focus on product quality as a major objective.

2. Experience Sharing

Issue

There is a deficiency in documentation and broad dissemination of information on success/failure experience and related subjects throughout the Government/Industry team.

Recommendations

- Establish a small government/industry committee to study this problem and develop short/long-range solutions.

3. Training - Motivation

Issue

Greater emphasis on personnel training and motivation is needed to insure improved productivity and quality in space system programs.

Recommendations

- Prospective contractor should be asked to submit their plans for training programs in their proposals.

- Government should develop recognition programs for contractors who demonstrate effective and innovative training and motivation programs.

- Government should publicize those programs which it finds have demonstrated superior training and motivational effectiveness.

4. Funding Motivation

Issue

Motivation/Problem - solving activities are often not contractually funded.

Recommendations

- Such efforts should be supported by DOD.

5. Sub Tier Suppliers

Issue

Sub tier and bulk suppliers are a major factor in high defect rates, due to insufficient motivation toward ach'eving high quality in products.

Recommendations

- Institute a joint government/ industry campaign to emphasize the importance of quality.

CLOSING REMARKS

Maj. Gen. James W. Stansberry
DCS/Contracting and Manufacturing
Air Force Systems Command

CLOSING ADDRESS

Maj. Gen. James W. Stansberry
DCS/Contracting and Manufacturing
Air Force Systems Command

Our nation has a very serious problem. Things cost too much and they don't always work right. That is described by people who make more than 40 cents an hour as a big productivity problem. Often times in Mission Assurance or Quality Assurance we get very narrow in our definition...maybe too narrow. I was delighted to see that this conference talked about Mission Assurance as it did last time. I will submit to you that there can't be important productivity without Mission Assurance, meaning: does the stuff work as intended! If you think in terms of productivity (you've already looked at the charts, I'm told, earlier in the week) you'll see that the United States is not doing such a red hot job in terms of productivity. In the decades of the 60s the annual average growth rate of productivity per worker, as measured by output-over-input, was about 3% on a national scale. If you look in the decades of the 70s, it was about 2%. You know the tendency that I would have, and I think you would have, is to say, "Well, a 1% drop, what the hell it's only 1%". But if you equate that to 1% of what, in terms of our Gross National Product, our output, it means that somewhere along the way in the last ten years, when all of us were working so hard, we lost $400 billion. Those dollars are enough to do a lot of the things that we with our orientation, AIA, NSIA, NASA, and DOD, think very important for this country to do. The 400 billion bucks are gone!

Last July I was sitting in front of my television set having my evening work pill, and I heard President Carter. He had just come down from Camp David. He was talking about the necessity of restoring the country's spirit. He said that the productivity of the American worker is actually going down. That's got to be a very serious claim to those of us interested in mission assurance. It's a national problem that probably requires national solutions, and our leaders have to devise solutions at the top. But there is darn little that they can do unless they receive a lot of push from the bottom. In looking over the results of your workshops last night and this morning, it struck me all here are pushing, as I am at our level. That push has to result in increased productivity if we are going to continue to defend this country properly. I cannot subscribe in any way to any thesis that says that you can be a first rate military power - and second rate in industrial productivity. It is not going to happen. So you start thinking a little bit about what we can do about it. Productivity, according to all the experts, and I'm no one, - the people over in labor - people in the Department of Commerce - people in government - people in academia - all seem to agree that productivity comes from technology, it comes from capital, and it comes from labor. And again, if I look over your workshops, I note the emphasis that you've accorded to these three areas, probably more on technology and labor than on capital, and considering the gathering, I think that's quite appropriate. So we see a national problem that has a great impact on the Department of Defense and on the Air Force. That problem sets the mood, sets the environment in which we make our decisions.

Now lets move from the national level. Perhaps we should discuss the Air Force concerns. That makes me think about my boss, General Slay, and by the way, let the record reflect that I never never, ever again want to hear the term "Slay Initiative". Boy, am I up to here with that! I say that not because my retirement papers are going to be submitted at noon (hopefully they aren't), but because the things we are trying to do in the area of productivity, in the area of manufacturing, in the area of quality assurance, reliability, maintainability and our contractual methods are not "Slay Initiatives". They are "Air Force Initiatives", the whole Air Force! General Kelly Burke testified to that effect in Congress a couple of weeks ago. So if you're sweating out Slay retiring, or Stansberry retiring, find another solution. The Air Force initiatives are going to be with us a long time. I think you'll decide they aren't so bad if we get a chance to talk more to each other about them. From the viewpoint of the command now, we have to have an obvious interest in productivity, in component parts,

mission assurance, quality - why? Obvious: We spend $16 billion a year on hardware; we have 300,000 contractual actions a year. Of course most of those are little ones, you know, beans and bullets-- but we have about 2,000 contractual actions at over $10,000 apiece, and we have maybe 50 or 60 that get way up there over the $100 million mark. A lot of money to be spent for a lot of hardware.

Like other customers, our hardware doesn't always work right either. General Henry and others within government and industry, have shared with each other during the last few days some of the problems. These problems are not isolated to strictly space vehicles, satellites, and missiles; we've had problems that fall across the board.

Sometimes the problems are the little things that shouldn't go wrong. Why should aluminum be soft? You wouldn't think that after all the years of processing aluminum we would get a big batch into our system that hadn't been properly quenched, and as a result lost some of its hardness. A real problem for the Air Force and other services. We've had airplanes whose controls jammed because a sealed area was sealed with dirt trapped inside. It hadn't been cleaned. We've had engines on airplanes take off without the airplane. I don't wish to go on with any litany of troubles.

The other side of the coin has to be that American arms are the standard of the world. But we still have a long way to go. From the perspective of the command, we've got a big chunk of the act - 16 billion bucks worth of hardware... We want to spend it wisely, we want what we paid for to work properly - a very simple, straight forward approach. Now you might say at this point (I said I'd tell you a little about personal perspective), why is Stansberry talking about all this quality stuff? He's never been in Quality in his whole life! But I want to tell you I have. My relation to Quality Assurance, and this point is key to my pitch, started when I was about 14 years old. My mother worked in a QA work force in a plant in Buffalo that produced depth charges. Naturally, as a young teenager in World War II, I was pretty proud of the old lady working at making sure those things worked right. Even they had problems. It must have been the height of aggravation to go find an enemy submarine and shoot a lot of depth charges at them and find the depth charges didn't work! What was the problem there? The gauges that were used to clear parts were not properly calibrated. A little thing. A lot of people out there staking their lives on a mission, and because of a failure that hardware did not work. Later I had an opportunity to serve in a Japanese aircraft factory - Kawasaki - and I came away from there thinking "No wonder the Japanese proved to be such a potent fighting force in World War II". Those people understood quality workmanship. We were building T-33s on a government-to-government arrangement and their T-33s were a little faster than Lockheed's and the reason was the care, the extra time that went into the workmanship that went into the product. I came home (20 years ago) thinking it's not going to be long before the whole world realizes that the Japanese understand quality workmanship.

Those figures we talked about in terms of productivity - I was sort of shocked to hear the other day where the Americans are increasing their productivity 1.8 to 2% a year, the Japanese are increasing theirs 10% a year. And last year we had to send a team over to Japan and ask them, "Please explain to us again how to produce quality goods." That was kind of interesting. We know how, but some how or another we've forgotten. And now we are rediscovering what it's really like. Not only are we rediscovering in our own little circles but I think it's very heartening that now nationally we are seeing the words productivity and quality assurance pop up. Yesterday on the airplane I was reading Time magazine, I just had to bring this along, and I suggest maybe you ought to get a copy. "Stunning Turnaround in Tarrytown" showing how General Motors, at a plant in Tarrytown had a lot of problems. Workers and bosses were constantly at each other's throats; employee grievances outstanding against management totaling 2,000; tremendous reject rates; and inside a couple of years they turned it around! Part of this answer - it doesn't say this in the article - is the quality circles proposition. They got the workers

and the first line supervisors and gave them a chance to talk to each other about the job during company time. And somehow or another the thing started to happen. For example, they went into one unit that had 30 windshield installers. After the workers had been disciplined during the previous six months for poor work, during discussion it was revealed that each worker selected a different point around the windshield to begin applying the seal. One worker explained that he started where the radio antenna wires emerged from the windshield because, "To get a little extra adhesive, a puddle, and that stops leaks." Everybody stood around amazed, saying how simple and so right, and that's where the leaks are! They all decided that they would all do it that way and the reject rate went down dramatically, almost instantly.

That wasn't such a big deal, but what is a big deal that Time magazine and the national publications are beginning to react to the problems of American productivity, American quality. I think we are going to see a tremendous turnaround in the next several years. I think we'll soon get to the point (it might take us several years) that once again, American products are the standard of the world. American productivity is what everyone shoots for. American quality is number one! It's really got to happen.

In any event, with some of this interest in quality, I volunteered for a job once, chairman of the DOD Quality Assurance Council! I lasted one day and was transferred. The heart of the problem that the quality assurance work force has always had is summarized in this question - who is Mr. Quality Assurance in the Department of Defense? Ask that question of most people and you'll get an answer kind of like "Gee, I know who he used to be but he got sick". Something like that. We don't have, haven't had anybody at the top around whom all people concerned with quality can rally. We haven't had a daddy rabbit; we haven't had a strong voice...

(At this point, General Stansberry cited the Quality Horizons report written by a group headed by Col B. Weiss. One of the recommendations was to appoint a chief of Product Assurance at the command level. General Stansberry stated that such a position would be created and staffed before the summer was out. He went on to describe the type of individual needed for this job.)

We know that he's going to have to be a special kind of guy. He's going to have to be able to understand the techniques he'll be working with - he's going to have to be able to handle the power he'll be given. He'll have to be a very articulate and able person. It will be a small office that will encompass reliability, maintainability and quality assurance at least initially. It will be a small office with a great deal of authority and power.

The second thing that we are going to do is to try to correct the imbalance between the front end and the back end, and put more emphasis on the engineering on the front end, and less emphasis on the inspection of the back end. I remember, as a captain at Kawasaki, I was new at all this stuff. I was in there a couple of days, when I decided that one thing you are supposed to do is go out and look at the airplane now and then if you are supposed to be the Air Force plant representative. I went out there a few times, and I never saw any of my own QA guys out there. I went back to the head of our QA and asked, "Where are our guys? I'm up here looking at airplanes and I never see any of them looking at airplanes." He said "Hey, we inspect the contractor's system", (and think about that a little) and sure enough they were, reading technical orders and procedures and processes. That's a pretty good answer but after awhile you say it sounds too good. So I told them, "Inspect your system by going out to look at the airplanes at least occasionally". I think some product orientation basis will always be needed. So don't do away with important back end; it's just a matter of balance.

The third thing we are going to do is be a lot more attentive to the needs of our work force in terms of training. We've really done a poor job, I think, in DOD - certainly at Air Force Systems Command, of offering training and upgrading of our work force. They didn't get any training to speak of in software, and look at all of the software problems we

face. If you look at the profile of the whole work force, they are distinctly, definitely, by anybody's definition, undertrained. Ther have been very few people coming in to our work force. It's a poor place to be. How do you ever get promoted if there is nobody on top taking care of you? And we've had a few people coming in. This fall we'll launch a quality intern program. We're going to bring new people into work force as interns, train them using our resources, I'm sure tapping industry resources and using the resources of other government agencies. It will start off relatively slow, but we will still have 30 or 40 new people in the work force by the time late fall or Christmas comes around. We're very excited about that.

We're going to do a much better job of linking our business methods with our technical methods and you've heard about this in terms of product assurance parameters, or perhaps, called a warranty. As a result of this recommendation we said, "Look, maybe we ought to get together and talk about this subject while we are not in the heat of completion or negotiation ." We got representatives of several companies together and said, "What would be a good way for the Air Force to go about getting more assurance from the contractor that the stuff is going to work?

We made up several important first principles to start with. One of the principles was good things cost money at the front end, and the customer better understand that. We do understand it, and we're willing to pay it. After laying out these first principles, we investigated 32 candidate programs where we thought a form of warranty or a form of incentive could be used. We got a lot of very valuable input from industry and we are now pursuing that. In addition, we took the essence of our deliberations over several meetings and reduced it to a handbook, our people in the program offices can use and industry can use in negotiating sound product performance parameters for use in our contracts. I think this offers great promise. What we don't want is something to break and then stick to the contract of the 60s. What we do want is for it not to break and we've had some experience.

The ARC/164 Radio comes to mind. A few years ago we had radios, UHF radios in our aircraft that had a mean-time-between failures of 30 to 50 hrs. of operation. This was just eating us alive with maintenance costs. After some competitive bidding and prototying, we bought a radio from Magnavox and an appropriate incentive in the contract, laid on them what some people thought was a laudable requirement. We now have the ARC/164 radio with a mean-time-between-failures of over 700 hrs! It can work! It takes some resolve on the part of the customer, it takes some resolve on the part of industry. We're going to get there.

Now my over-all message to you is not any of these little details. It really goes like this...we perceive a national problem - the problem of productivity in the US. We are not going to sit by in the Air Force and leave it unaddressed. We are willing to devote our money and attention to technology, making capital available (front-end-money) helping, whenever we can, our labor force to do it right - because they want to - I'm convinced of that! The days when a guy can say "Hey, who the hell's in charge of Quality Assurance around here?", and not get an answer, are over, as far as the Air Force Systems Command is concerned.

CLOSING REMARKS

Col. Norman Niederman
Director, Manufacturing and Quality Assurance
A. F. Space Division (AFSC)

CLOSING BUSINESS

(Col. Norman Neiderman)

As a chairman of this conference plus being the anchorman on the Agenda, I have a doubly rewarding position, and as my wife well knows having the last word in any discussion is most advantageous. So, I plan to make the most of it!

General Henry said the first day - "Finding solutions to Mission Assurance Problems is our business". We have, in just one week, identified numerous problems that will take time to resolve. What is done to implement the recommendations proposed by the individual workshops is up to each and everyone of us. What we do will very well be reflected on future activities in space. How we follow and embrace the guidelines, recommendations, procedures and standards that have evolved from this Mission Assurance Conference will be the ultimate test of how successful this conference has been.

What I'm saying is we still have a lot of work to do. We can't walk away from this meeting and think that the issues we've discussed will take care of themselves, or that the problems will disappear. I dare say that most of us will at one time or another be directly or indirectly involved, and when you are - step up and accept the challenge. We collectively can make the difference between the improvement of our track record in Space, or the degradation of our capabilities and available resources. Many of you will be called on to help in completing tasks or action items. When you are, please help.

As for your immediate activities (speaking for the sponsors of this conference) we intend to read, analyze, and respond to each and every critique sheet as well as the workshop recommendation. At the conclusion, today, we will start compiling the proceedings. They will be edited, and retyped, if necessary, and published. All conference registrants will receive a copy.

We are also going to prepare an executive summary in May. If you would like to get a copy of this, please place your name and address on a separate piece of paper that says, "Executive Summary", located at the Registration Desk.

I would like to especially thank General Henry, Mr. Plummer, General Robinson, and General Stansberry for taking the time from their busy schedules to talk to us. I would like to thank the opening day panel on past and future challenges of Mission Assurance. They were truly inspirational. I would also like to thank the chairmen who so adroitly conducted their workshops - and the hardworking coordinators who, up until the conference, made sure the chairmen were on schedule with all of the many tasks associated with developing a workshop. And to the planning committee who worked so hard and met so many times to assure this conference was a success - Thanks. Our Administrative staff also deserves sincere thanks. And lastly, the participants, the speakers and the spoken to, without you there would not be a conference - thank you.

I believe we have a great team effort ar. I am personally confident that this Air Force/NASA/Industry approach to solving our concerns will be most rewarding. I also want to recognize the National Security Industrial Association and the Aerospace Industries Association for sponsorint this conference, and the continuing contribution that these organizations are making to the advancement of national objectives.

So please let me remind you, this is not the end of the conference activity, but the continuing effort to assure that through creativity, innovation, enthusiastic implementation both by industry and government, and perceptive and dynamic management, we can achieve Mission Assurance. And now, I declare this meeting adjourned.

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